Rai Technology University

ENGINEERING MINDS

Software Engineering

Subject: SOFTWARE ENGINEERING **Credit: 4**

SYLLABUS

Overview:
Introduction: FAQs about Software Engineering; Professional and Ethical Responsibility; Software Process: Models; Process Iteration, Specification, Software Design and Implementation; Verification & Validation; Software Evolution; Automated Process Support.

Software Project Management and Requirements
Project Management: Management Activities, Project Pl Software Project Management and Requirements Project Management: Management Activities, Project Planning, Project Scheduling, Risk Management; Software Requirements: Functional and Non-Functional Requirements, User Requirements, System Requirements, Requirements Document; Requirements Engineering Process: Feasibility Studies, Requirements Elicitation and Analysis, Requirements Validation, Requirements Management.

System Models, Software Prototyping and Specifications
System Models, Software Prototyping and Specifications System models: Context, Behavioural, Data, and Object models, CASE Workbenches; Software Prototyping: Prototyping in the Software Process, Rapid Prototyping Techniques, User Interface Prototyping; Specifications: Formal Specification in the Software Process, Interface Specification, Behavioural Specification.

Architectural Design
Introduction: System Structuring; Control Models; Modular Decomposition; Domain- Specific Architectures; Distributed Systems Architectures: Multiprocessor Architectures; Client-Server Architectures, Distributed Object Architectures; CORBA (Common Object Request Broker Architecture)

Software Design
Object Oriented Design: Objects and Object Classes, Object-Oriented Design Process, Design Evolution; Real Time Software Design: Systems Design, Real-Time Executives, Monitoring and Control Systems, Data Acquisition Systems; Design with Reuse: Component-Based Development, Application Families, Design Patterns; User Interface Design: Principles, User Interaction, Information Presentation, User Support, Interface Evaluation.

Verification, Validation and Testing
Verification and Validation (V & V): Static and Dynamic V & V, V & V Goals, V & V vs. Debugging, Software Inspections / Reviews, Clean-Room Software Development; Software Testing: Defect Testing, Integration Testing, Interface Testing, Object-Oriented Testing, Testing Workbenches

Managing People
Introduction; Limits to Thinking; Memory Organization; Knowledge Modeling; Motivation; Group Working; Choosing and Keeping People; the People Capability Maturity Model

Software Cost Estimation and Quality Management
Software Cost Estimation: Productivity, Estimation Techniques, Algorithmic Cost Modelling, Project Duration and Staffing. Quality Management: Quality Assurance and Standards, Quality Planning, Quality Control, Software Measurement and Metrics; Process Improvement: Process and Product Quality, Process Analysis and Modelling, Process Measurement, the SEI Process Maturity Model, and Process Classification

Evolution
Legacy Systems: Structures, Design, and Assessment; Software Change: Program Evolution Dynamics, Software Maintenance, Architectural Evolution; Software Re- Engineering: Source Code Translation, Reverse Engineering, Program Structure Improvement, Program Modularization, Data Re-Engineering; Configuration Management

Suggested Readings:

1. Software Engineering: An Engineering Approach, by J.F.Peters and W. Pedrycz, Publisher: John Wiley and Sons
2. Software Engineering: A Practitioner's Approach by Roger Pressman, Publisher: McGraw-Hill
3. Fundamentals of Software Engineering by Ghezzi, Jayazeri, and Mandrioli, Publisher: Prentice-Hall
4. Software Engineering Fundamentals by Ali Behforooz, and Frederick J.Hudson, Publisher: Oxford University Press

COURSE OVERVIEW

Software systems are now ubiquitous. Virtually all electrical equipment now includes some kind of software; software is used to help run manufacturing industry, schools and universities, health care, finance and government; many people use software of different kinds for entertainment and education. The specification, development, management and evolution of these software systems make up the discipline of *software engineering.*

Even simple software systems have a high inherent complexity so engineering principles have to be used in their development. Software engineering is therefore an engineering discipline where software engineers use methods and theory from computer science and apply this cost-effectively to solve difficult problems. These difficult problems have meant that many software development projects have not been successful. However, most modern software provides good service to its users; we should not let high-profile failures obscure the real successes of software engineers over the past 30 years.

Software engineering was developed in response to the problems of building large, custom software systems for defence, government and industrial applications. We now develop a much wider range of software from games on specialized consoles through personal PC products and web-based systems to very large-scale distributed systems. Although some techniques that are appropriate for custom systems, such as object-oriented development, are universal, new software engineering techniques are evolving for different types of software. It is not possible to cover everything in one book so I have concentrated on universal techniques and techniques for developing large-scale systems rather than individual software products.

Although the book is intended as a general introduction to software engineering, it is oriented towards system requirements engineering. I think this is particularly important for software engineering in the 21st century where the challenge we face is to ensure that our software meets the real needs of its users without causing damage to them or to the environment.

The approach that I take in this book is to present a broad perspective on software engineering and I don't concentrate on any specific methods or tools. There are no simple solutions to the problems of software engineering and we need a wide spectrum of tools and techniques to solve software engineering problems.

Software Engineering

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LESSON 1:
INTRODUCTION

Getting Started With Software Engineering

Objectives

- To introduce software engineering and to explain its importance
- To set out the answers to key questions about software engineering
- To introduce ethical and professional issues and to explain why they are of concern to software engineers

Topics Covered

- FAQs about software engineering
- Professional and ethical responsibility

Software Engineering

The economies of ALL developed nations are dependent on software

More and more systems are software controlled

Software engineering is concerned with theories, methods and tools for professional software development

Software engineering expenditure represents a significant fraction of GNP in all developed countries

Software Costs

Software costs often dominate system costs. The costs of software on a PC are often greater than the hardware cost

Software costs more to maintain than it does to develop. For systems with a long life, maintenance costs may be several times development costs

Software engineering is concerned with cost-effective software development

FAQs About Software Engineering

What is software?

What is software engineering?

What is the difference between software engineering and computer science?

What is the difference between software engineering and system engineering?

What is a software process?

What is a software process model?

What are the costs of software engineering?

What are software engineering methods?

What is CASE (Computer-Aided Software Engineering)

What are the attributes of good software?

What are the key challenges facing software engineering?

What is Software?

Computer programs and associated documentation

Software products may be developed for a particular customer or may be developed for a general market

Software products may be

- Generic - developed to be sold to a range of different customers
- Bespoke (custom) - developed for a single customer according to their specification

What is Software Engineering?

Software engineering is an engineering discipline, which is concerned with all aspects of software production

Software engineers should adopt a systematic and organised approach to their work and use appropriate tools and techniques depending on the problem to be solved, the development constraints and the resources available

What is The Difference Between Software Engineering and Computer Science?

Computer science is concerned with theory and fundamentals; software engineering is concerned with the practicalities of developing and delivering useful software

Computer science theories are currently insufficient to act as a complete underpinning for software engineering

What is The Difference Between Software Engineering and System Engineering?

System engineering is concerned with all aspects of computer-based systems development including hardware, software and process engineering. Software engineering is part of this process

System engineers are involved in system specification, architectural design, integration and deployment

What is a Software Process?

A set of activities whose goal is the development or evolution of software

Generic activities in all software processes are:

- Specification : what the system should do and its development constraints
- Development : production of the software system
- Validation : checking that the software is what the customer wants
- Evolution : changing the software in response to changing demands

What is a Software Process Model?

A simplified representation of a software process, presented from a specific perspective

Examples of process perspectives are

- Workflow perspective : sequence of activities

- Data-flow perspective : information flow
- Role/action perspective : who does what

Generic Process Models

- Waterfall
- Evolutionary development
- Formal transformation
- Integration from reusable components

What are The Costs of Software Engineering?

Roughly 60% of costs are development costs, 40% are testing costs. For custom software, evolution costs often exceed development costs

Costs vary depending on the type of system being developed and the requirements of system attributes such as performance and system reliability

Distribution of costs depends on the development model that is used

What are Software Engineering Methods?

Structured approaches to software development which include system models, notations, rules, design advice and process guidance

Model Descriptions
Descriptions of graphical models, which should be produced

Rules
Constraints applied to system models

Recommendations
Advice on good design practice

Process Guidance
What activities to follow

What is Case (Computer-aided Software Engineering)?

Software systems which are intended to provide automated support for software process activities. CASE systems are often used for method support

Upper-CASE
Tools to support the early process activities of requirements and design

Lower-CASE
Tools to support later activities such as programming, debugging and testing

What are The Attributes of Good Software?

The software should deliver the required functionality and performance to the user and should be maintainable, dependable and usable

Maintainability
Software must evolve to meet changing needs

Dependability
Software must be trustworthy

Efficiency
Software should not make wasteful use of system resources

Usability
Software must be usable by the users for which it was designed

What are the Key Challenges Facing Software Engineering?

Coping with legacy systems, coping with increasing diversity and coping with demands for reduced delivery times

Legacy Systems
Old, valuable systems must be maintained and updated

Heterogeneity
Systems are distributed and include a mix of hardware and software

Delivery
There is increasing pressure for faster delivery of software

Professional and Ethical Responsibility

Software engineering involves wider responsibilities than simply the application of technical skills

Software engineers must behave in an honest and ethically responsible way if they are to be respected as professionals

Ethical behaviour is more than simply upholding the law.

Issues of Professional Responsibility

Confidentiality
Engineers should normally respect the confidentiality of their employers or clients irrespective of whether or not a formal confidentiality agreement has been signed.

Competence
Engineers should not misrepresent their level of competence. They should not knowingly accept work, which is out with, their competence.

Intellectual Property Rights
Engineers should be aware of local laws governing the use of intellectual property such as patents, copyright, etc. They should be careful to ensure that the intellectual property of employers and clients is protected.

Computer Misuse
Software engineers should not use their technical skills to misuse other people's computers. Computer misuse ranges from relatively trivial (game playing on an employer's machine, say) to extremely serious (dissemination of viruses).

ACM/IEEE Code of Ethics

The professional societies in the US have cooperated to produce a code of ethical practice.

Members of these organisations sign up to the code of practice when they join.

The Code contains eight Principles related to the behaviour of and decisions made by professional software engineers, including practitioners, educators, managers, supervisors and policy makers, as well as trainees and students of the profession.

Code of Ethics : Preamble

Preamble

- The short version of the code summarizes aspirations at a high level of the abstraction; the clauses that are included in

the full version give examples and details of how these aspirations change the way we act as software engineering professionals. Without the aspirations, the details can become legalistic and tedious; without the details, the aspirations can become high sounding but empty; together, the aspirations and the details form a cohesive code.

- Software engineers shall commit themselves to making the analysis, specification, design, development, testing and maintenance of software a beneficial and respected profession. In accordance with their commitment to the health, safety and welfare of the public, software engineers shall adhere to the following Eight Principles:

Code of Ethics : Principles

1. Public
Software engineers shall act consistently with the public interest.

2. Clients and Employer
Software engineers shall act in a manner that is in the best interests of their client and employer consistent with the public interest.

3. Product
Software engineers shall ensure that their products and related modifications meet the highest professional standards possible.

4. Judgment
Software engineers shall maintain integrity and independence in their professional judgment.

5. Management
Software engineering managers and leaders shall subscribe to and promote an ethical approach to the management of software development and maintenance.

6. Profession
Software engineers shall advance the integrity and reputation of the profession consistent with the public interest.

7. Colleagues
Software engineers shall be fair to and supportive of their colleagues.

8. Self
Software engineers shall participate in lifelong learning regarding the practice of their profession and shall promote an ethical approach to the practice of the profession.

Ethical Dilemmas
Disagreement in principle with the policies of senior management

Your employer acts in an unethical way and releases a safety-critical system without finishing the testing of the system

Participation in the development of military weapons systems or nuclear systems

Key Points
Software engineering is an engineering discipline, which is concerned with all aspects of software production.

Software products consist of developed programs and associated documentation. Essential product attributes are maintainability, dependability, efficiency and usability.

The software process consists of activities, which are involved, in developing software products. Basic activities are software specification, development, validation and evolution.

Methods are organised ways of producing software. They include suggestions for the process to be followed, the notations to be used, and rules governing the system descriptions, which are produced and design guidelines.

CASE tools are software systems, which are designed to support routine activities in the software process such as editing design diagrams, checking diagram consistency and keeping track of program tests which have been run.

Software engineers have responsibilities to the engineering profession and society. They should not simply be concerned with technical issues.

Professional societies publish codes of conduct, which set out the standards of behaviour expected of their members.

Activity

What are the four important attributes, which all software products have? Suggest four attributes, which may be significant.

Activity

What are the four important attributes, which all software products should have? Suggest four other attributes, which may be significant.

Activity

Software engineering methods only became widely used when CASE technology became available to support them. Suggest five types of method support, which can be provided by CASE tools.

Activity

Explain why system-testing costs are particularly high for generic software products, which are sold to a very wide market.

Activity

Apart from the challenges of legacy systems, heterogeneity and rapid delivery, identify other problems and challenges that software engineering is likely to face in the 21st century.

Notes -

LESSON 2 AND 3:
SOFTWARE PROCESSES

Coherent Sets of Activities For Specifying, Designing, Implementing And Testing Software Systems

Objectives

- To introduce software process models
- To describe a number of *generic* process models and when they may be used
- To outline lower-level process models for requirements engineering, software development, testing, and evolution
- To introduce CASE technology to support software process activities

Topics Covered

- Software process models
- Process iteration
- Software specification
- Software design and implementation
- Software verification & validation
- Software evolution

Automated process support

The Software Process

A structured set of activities required to develop a software system

- Specification
- Design
- Validation / verification
- Evolution

A software process model is an abstract representation of a process. It presents a description of a process from some particular perspective

Models should be as simple as possible, but no

Simpler. – A. Einstein

Generic Software Process Models

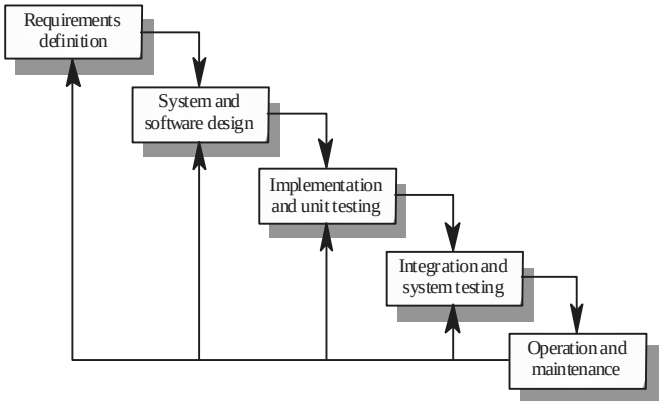
The Waterfall Model : separate and distinct phases of specification and development

Evolutionary Development : specification and development are interleaved

Formal Systems Development : a mathematical system model is formally transformed to an implementation

Reuse-Based Development : the system is assembled from existing components

Waterfall Model



Waterfall Model Problems

Inflexible partitioning of the project into distinct stages makes it difficult to respond to changing customer requirements.

Thus, this model is only appropriate when the requirements are well understood.

In general, the drawback of the waterfall model is the difficulty of accommodating change after the process is underway.

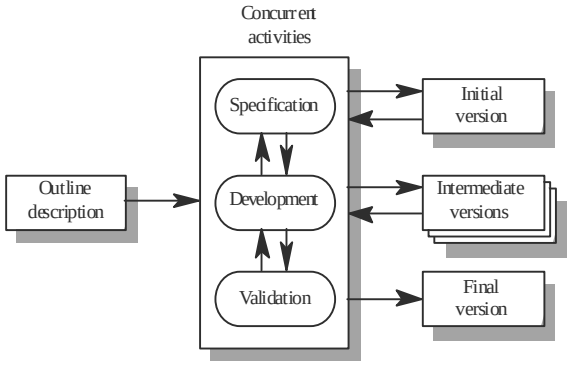
Evolutionary Development

Exploratory Development *– objective is to work with customers and to evolve a final system from an initial outline specification. (Development starts with well-understood parts of system.)

Throwaway Prototyping – objective is to understand the system requirements. (Prototyping focuses on poorly understood requirements.)

- Also known as exploratory programming, or evolutionary prototyping

Evolutionary development



Potential Problems

- Lack of process visibility
- Final version/prototype is often poorly structured
- Special skills (e.g., in languages for rapid prototyping) may be required

Applicability

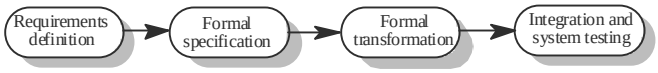
- For small or medium-size interactive systems
- For parts of large systems (e.g., the user interface)
- For short-lifetime systems (in case of exploratory development)

Formal Systems Development

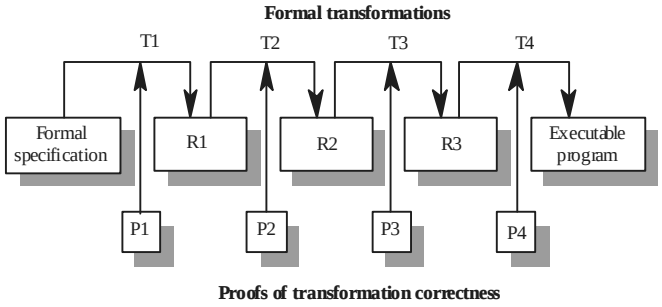
Based on the transformation of a mathematical specification through different representations to an executable program

Transformations are "correctness-preserving" so it is possible to show that the program conforms to its specification

Embodied in Mills' "Clean room" approach to software development



Formal Transformations



Problems

- Need for specialized skills and training to apply the technique
- Difficult to formally specify some aspects of the system such as the user interface (thus, focus is usually limited to functional requirements)

Applicability

- Critical systems, especially those where a safety or security case must be made before the system is put into operation
- Critical parts of large systems

Reuse-oriented Development

Based on systematic (as opposed to serendipitous) reuse of existing software units

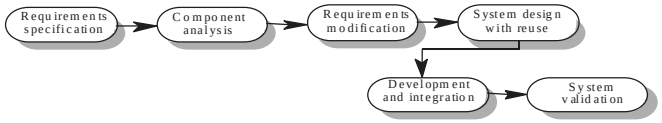
Units may be:

- Procedures or functions (common for past 40 years)
- Components ("component-based development")
- Core elements of an application ("application family")
- Entire applications — COTS (Commercial-off-the-shelf) systems

May also be based on use of design patterns

- Process stages
- Reusable software analysis
- Requirements modification
- System design with reuse
- Development and integration

This approach is becoming more important, but experience is still limited.



Process Iteration

For large systems, requirements ALWAYS evolve in the course of a project.

Thus, process iteration is ALWAYS part of the process.

Iteration can be incorporated in any of the generic process models

Two other approaches that explicitly incorporate iteration:

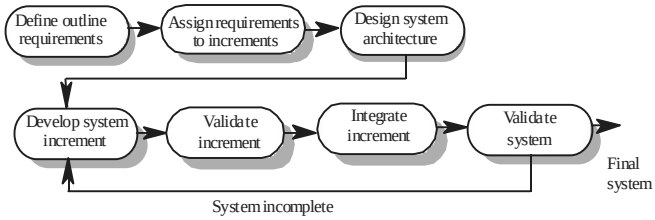
- Incremental development
- Spiral development

Incremental Development

Rather than deliver the system as a single unit, the development and delivery is broken down into increments, each of which incorporates part of the required functionality.

User requirements are prioritised and the highest priority requirements are included in early increments.

Once the development of an increment is started, its requirements are "frozen" while requirements for later increments can continue to evolve.



Incremental Development Advantages

Useful functionality is delivered with each increment, so customers derive value early.

Early increments act as a prototype to help elicit requirements for later increments.

Lower risk of overall project failure

The highest priority system services tend to receive the most testing.

Potential Problem

Requirements may NOT be partitionable into stand-alone increments.

Extreme Programming (Beck '99)

Recent evolution of incremental approach based on

- Development and delivery of very small increments of functionality
- Significant customer involvement in process
- Constant code improvement
- Ego less, pair-wise programming

NOT document-oriented

Gaining acceptance in some small organizations

Representative of the "agile" development paradigm

Boehm's Spiral Development

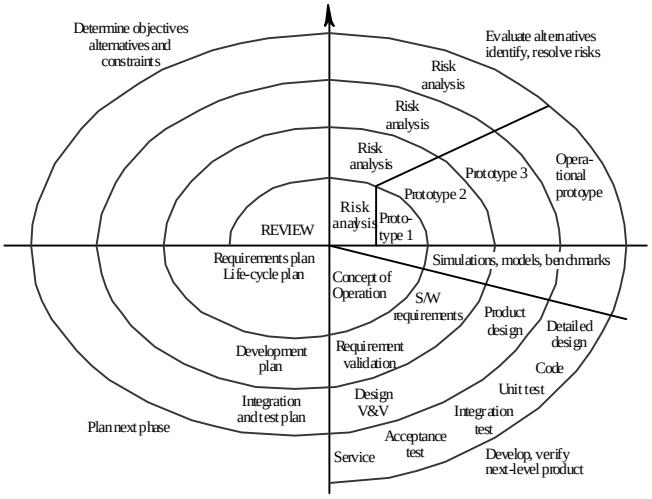
Process is represented as a *spiral* rather than a sequence of activities.

Each loop in the spiral represents a phase in the process.

No fixed phases such as specification or design — loops in the spiral are chosen depending on what is required

Explicitly incorporates *risk assessment and resolution* throughout the process

Spiral Model of the Software Process



Spiral Model Quadrants

Objective Setting : specific objectives for the phase are identified

Risk Assessment and Reduction : risks are assessed and activities put in place to reduce the key risks

Development and Validation : a development model for the system is chosen which can be any of the generic models

Planning : the project is reviewed and the next phase of the spiral is planned

Models for Fundamental Process Activities

Software specification/requirements engineering

Software development (design and implementation)

Software verification and validation

Software evolution

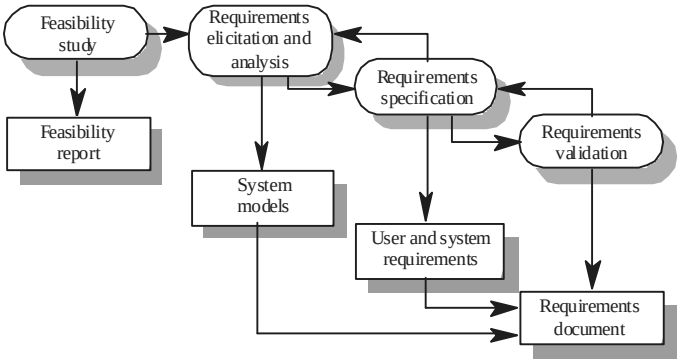
Software Specification

The process of establishing what services are required and the constraints on the system's operation and development

Requirements Engineering Process

- Feasibility (technical and otherwise) study
- Requirements elicitation and analysis
- Requirements specification (documentation)
- Requirements validation

The Requirements Engineering Process



Software Design and Implementation

The process of producing an executable system based on the specification

Software design – design a software structure that realizes the specification

Implementation – translate this structure into an executable program

The activities of specification, design, and implementation are closely related and may be inter-leaved.

Design Process Activities

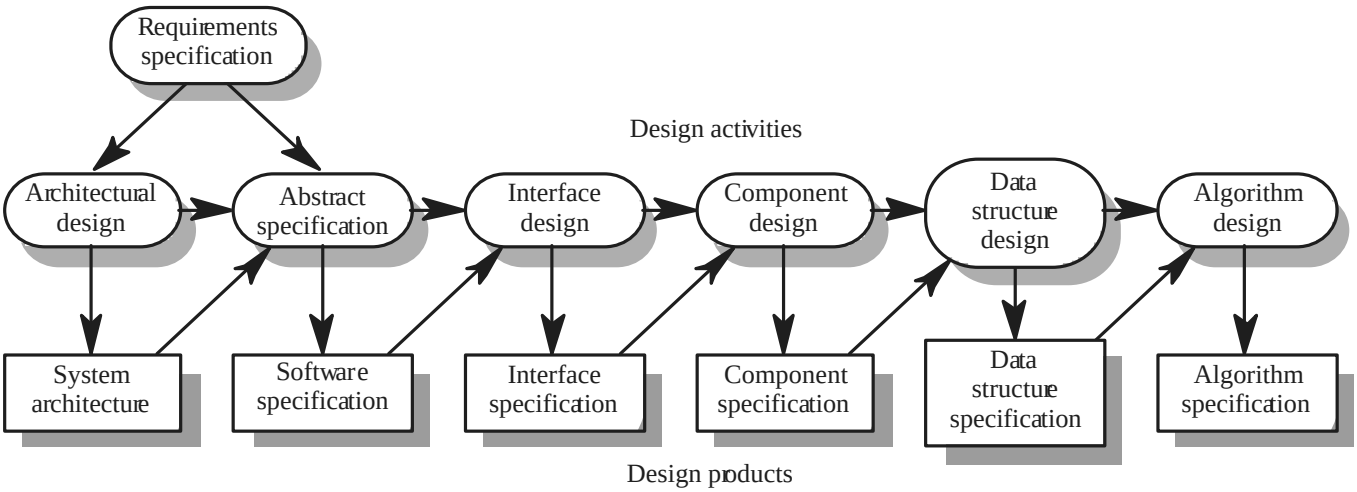
"High-Level" design activities

- Architectural design : subsystems and their relationships are identified
- Abstract specification : of each sub-system's services
- Interface design : among sub-systems

"Low-Level" design activities

- Component design : services allocated to different components and their interfaces are designed
- Data structure design
- Algorithm design

The Software Design Process



Design Methods

Systematic (canned) approaches to developing a software design

The design is usually documented as a set of graphical models

Possible Models

- Data-flow model
- Entity-relation-attribute model
- Structural model
- Object models

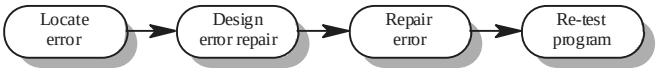
Programming and Debugging

Translating a design into a program and removing errors from that program (compare with Clean room SE)

Programming is a "personal activity" - a there is no generic programming process

Programmers carry out some program testing to discover faults ("unit testing"), and remove faults in the debugging process

The Debugging Process



Software Verification & Validation

Verification and validation (V&V) determines whether or not a system

(1) conforms to its specification and (2) meets the needs of the customer.

Involves inspection / review processes and (machine-based) testing

Testing involves executing system elements with test cases that are derived from specifications and/or program logic.

Testing Stages

Unit/Module testing : individual function/procedures are tested

(unit/module) Integration testing

Component testing : functionally related units/modules are tested together

(component) Integration testing

Sub-system/product testing : sub-systems or products are tested

(product/sub-system) Integration testing

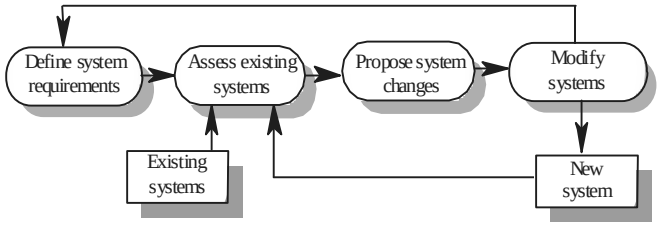
System testing : testing of the system as a whole, including user acceptance test

Software Evolution

Software is inherently flexible and subject to change.

As requirements change through changing business circumstances, the software that supports the business must also evolve and change.

The distinction between development and evolution is increasingly irrelevant as fewer and fewer systems are completely new.



Automated Process Support (Case)

Computer-aided software engineering (CASE) is software to support software development and evolution processes

Activity automation

- Graphical editors for system model development
- Data dictionaries for name management
- GUI builders for user interface construction
- Debuggers to support program faultfinding
- Automated translators to generate new versions of a program

(e.g., restructuring tools)

CASE Technology

CASE technology has led to significant improvements in the software process, but not the order of magnitude improvements that were once predicted.

- Software engineering involves design activity requiring creative thought : this is not readily automatable
- Software engineering is a team activity and, for large projects, much time is spent in team interactions. CASE technology does not support this well.

CASE Classification

Classification helps us understand the different types of CASE tools / systems and their support for process activities

Functional perspective : tools are classified according to their specific function

Process perspective : tools are classified according to process activities that are supported

Integration perspective : CASE systems are classified according to their breadth of support for the software process

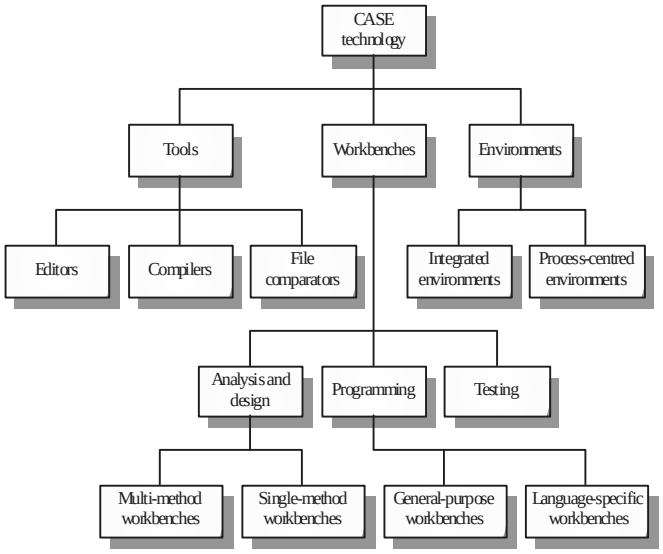
CASE Integration

Tools – support individual process tasks such as design consistency checking, text editing, etc.

Workbenches : support a process phase such as specification or design, Normally include a number of integrated tools

Environments : support all or a substantial part of an entire software process. Normally include several integrated workbenches

Tools, Workbenches, Environments



Key Points

Software processes are the activities involved in producing and evolving a software system. They are represented in a software process model.

Fundamental activities are specification, design and implementation, validation & verification, and evolution.

Generic models are very general process models representing different approaches to development.

Iterative process models describe the software process as a cycle of activities.

Requirements engineering is the process of establishing what services are required and the constraints on the system's operation and development.

Design and implementation processes produce an executable system based on the specification.

V&V involves checking that the system meets its specification and satisfies user needs.

Evolution is concerned with modifying the system after it is placed in use.

CASE technology supports software process activities

Activity

Giving reasons for your answer based on the type of system being developed, suggest the most appropriate generic software process model which might be used as a basis for managing the development of the following systems:

- A system to control anti –lock braking in a car.
- A virtual reality system to support software maintenance:
- A university accounting system that replaces an existing system;
- An interactive system for railway passengers that finds train times from terminals installed in stations.

Activity

Explain why programs which are developed using evolutionary development are likely to be difficult to maintain.

Activity

Suggest why it is important to make a distinction between developing the user requirements and developing the system requirements in the requirements engineering process.

Activity

Explain how both the waterfall model of the software process and the prototyping model can be accommodated in the spiral process model.

Activity

Describe the main activities in the software design process and the outputs of these activities. Using an entity- relation diagram, show possible relationships between the outputs of these activities.

Activity

What are the five components of a design method? Take any method which you know and describe its components. Assess the completeness of the method, which you have chosen.

Activity

Explain why a software system that is used in a real-world environment must change or become progressively less useful.

Activity

Design a process model for running system tests and recording their results.

Activity

Suggest how a CASE technology classification scheme may be helpful to managers responsible for CASE system procurement.

LESSON 4 AND 5:
PROJECT MANAGEMENT

Organizing, Planning and Scheduling Software Projects

Objectives

- To introduce software project management and to describe its distinctive characteristics
- To discuss project planning and the planning process
- To show how graphical schedule representations are used by project management
- To discuss the notion of risks and the risk management process

Topics Covered

- Management activities
- Project planning
- Project scheduling
- Risk management

Software Project Management

- Concerned with activities involved in ensuring that software is delivered on time, within budget and in accordance with the requirements of the organizations developing and procuring the software.
- Project management is needed because software development is always subject to budget and schedule constraints that are set by the organization developing the software.

Software Management Distinctions

- The product is intangible.
- The product is uniquely flexible.
- Software engineering is not recognized as an engineering discipline with the same status as mechanical, electrical engineering, etc.
- The software development process is not standardized.
- Many software projects are "one-off" projects.

Management Activities

- Proposal writing (to fund new projects)
- Project planning and scheduling
- Project costing and preparing bids
- Project monitoring and reviews
- Personnel selection and evaluation
- Report writing and presentations
- Attending lots and lots of meetings!

Management Commonalities

- These activities are not peculiar to software management.
- Many techniques of engineering project management are equally applicable to software project management.
- Technically complex engineering systems tend to suffer from most of the same problems as software systems.

Project Staffing

- May not be possible to appoint the ideal people to work on a project…

  •Project budget may not allow for use of highly paid staff.

  •Those with appropriate skills / experience may not be available.

  •An organization may wish to develop employee skills by assigning inexperienced staff.
- Managers have to work within these constraints especially when (as is currently the case) there is an international shortage of skilled IT staff.

Project Planning

- Probably the most time-consuming project management activity (or at least it should be).
- Continuous activity from initial concept to system delivery. Plans must be regularly revised as new information becomes available.
- Different types of sub-plans may be developed to support a main software project plan concerned with overall schedule and budget.

Types of Project Sub-plans

Plan	**Description**
Quality plan	Describes the quality procedures and standards that will be used in a project.
Validation plan	Describes the approach, resources and schedule used for system validation.
Configuration management plan	Describes the configuration management procedures and structures to be used.
Maintenance plan	Predicts the maintenance requirements of the system, maintenance costs and effort required.
Staff development plan.	Describes how the skills and experience of the project team members will be developed.

Project Planning

- "The *plan* is nothing – the *planning* is everything."

  – Dwight Eisenhower, on the D-Day invasion plan

Project Planning Process

```
Establish the project constraints
Make initial assessments of the project parameters
Define project milestones and deliverables
while project has not been completed or canceled loop
        Draw up project schedule
        Initiate activities according to schedule
        Wait (for a while)
        Revise estimates of project schedule
        Re-negotiate project constraints and deliverables
        if (problems arise) then
        Initiate technical review and possible revision
        end if
end loop
```

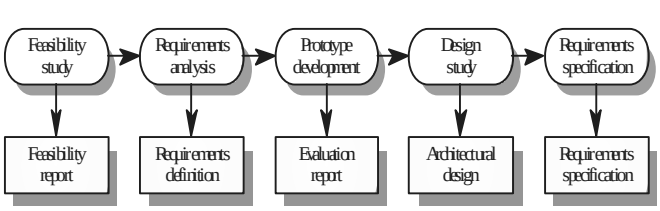
Project Plan Document Structure

- Introduction (goals, constraints, etc.)
- Project organisation
- Risk analysis
- Hardware and software resource requirements
- Work breakdown
- Project schedule
- Monitoring and reporting mechanisms

Activity Organization

- Activities in a project should be associated with tangible outputs for management to judge progress (i.e., to provide process visibility)
- Milestones are the unequivocal end-points of process activities.
- Deliverables are project results delivered to customers. (There are also internal deliverables.)
- The waterfall model allows for the straightforward definition of milestones *(*"a deliverable oriented model"*).*
- Deliverables are always milestones, but milestones are not necessarily deliverables

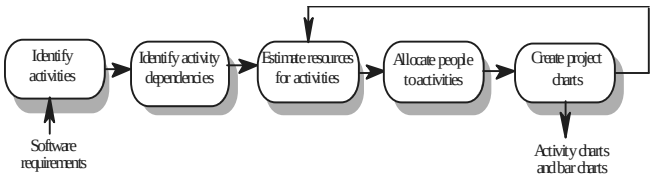
Milestones in The Re Process



Project Scheduling

- Split project into tasks and estimate time and resources required to complete each.
- Tasks should not be too small or too large they should last on the order of weeks for projects lasting months.
- Organize as concurrent activities to make optimal use of workforce.
- Minimize task dependencies to avoid potential delays.
- Dependent on project managers' intuition and experience

The Project Scheduling Process



Scheduling Problems

- Estimating the difficulty of problems, and hence the cost of developing solutions, is hard.
- Progress is generally not proportional to the number of people working on a task.
- Adding people to a late project can make it later. (due to coordination overhead)
- The unexpected always happens. Always allow for different contingencies in planning.

Bar Charts and Activity Networks

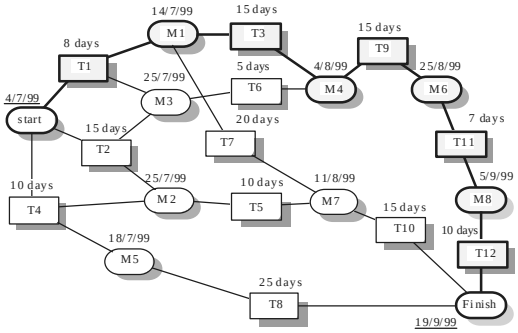
- Graphical notations are often used to illustrate project schedules.
- Activity charts (a.k.a. PERT* charts) show task dependencies, durations, and the critical path.
- Bar charts (a.k.a. GANTT charts) generally show resource (e.g., people) assignments and calendar time.

* Program Evaluation and Review Technique

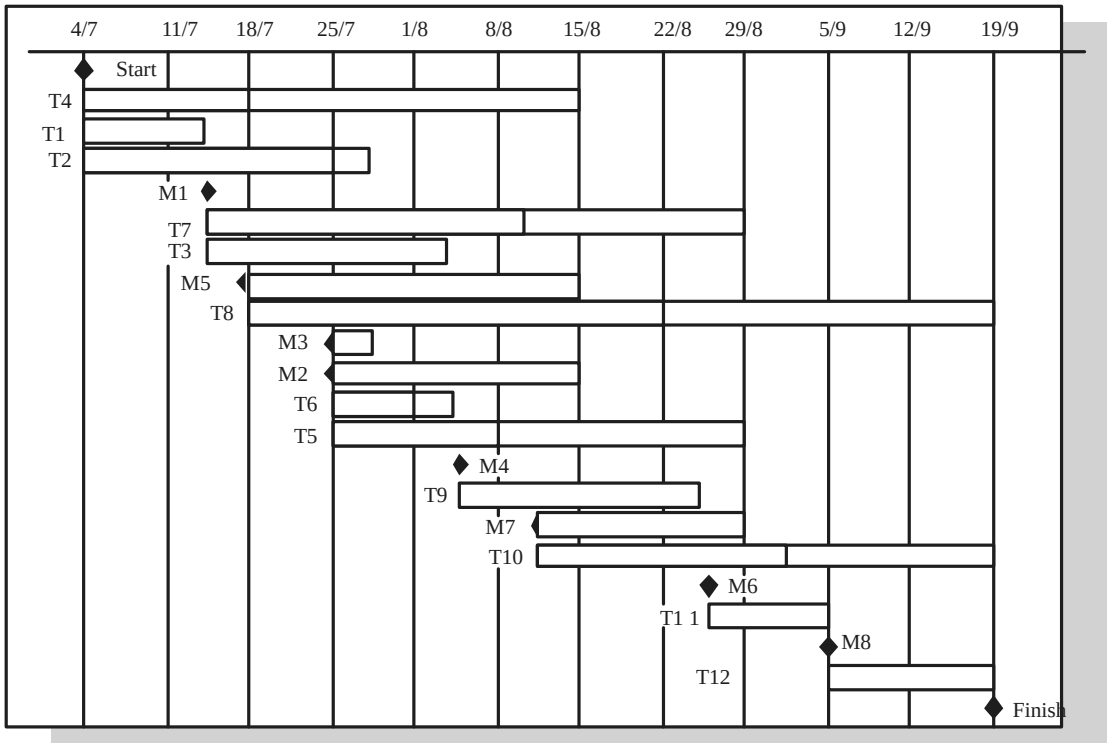
Task Durations and Dependencies

Task	Duration (days)	Dependencies
T1	8	
T2	15	
T3	15	T1 (M1)
T4	10	
T5	10	T2, T4 (M2)
T6	5	T1, T2 (M3)
T7	20	T1 (M1)
T8	25	T4 (M5)
T9	15	T3, T6 (M4)
T10	15	T5, T7 (M7)
T11	7	T9 (M6)
T12	10	T11 (M8)

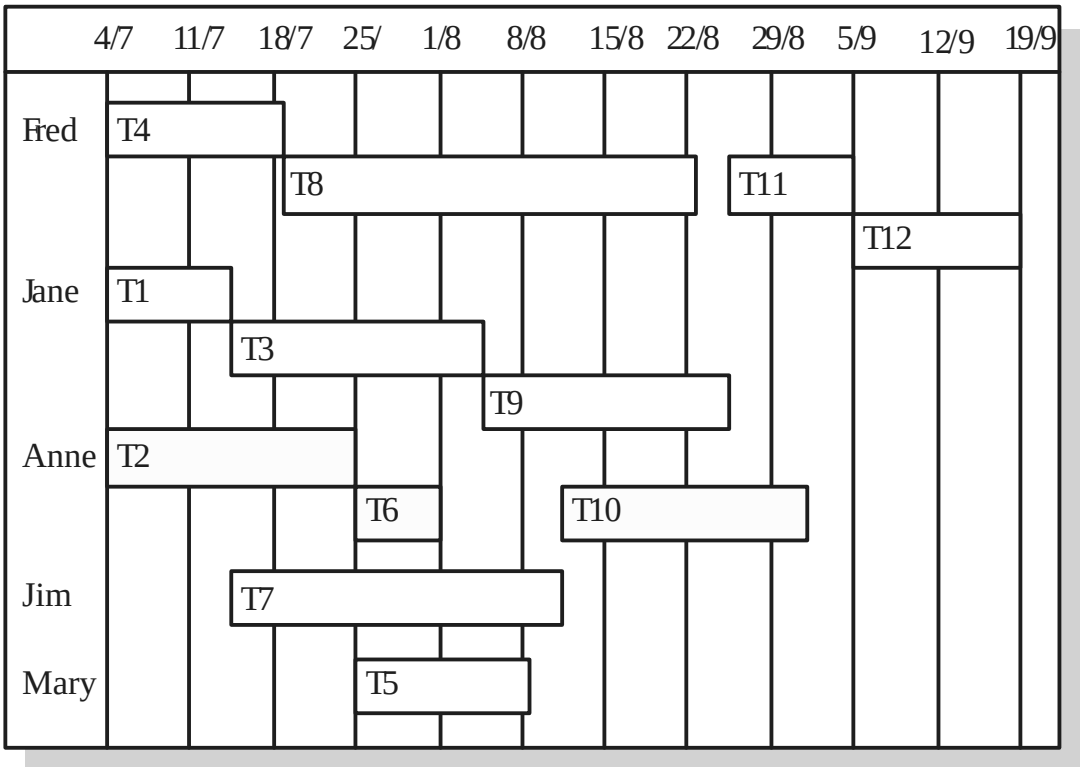
Activity Network



Activity Timeline



Staff Allocation



Risk Management

- Risk management is concerned with identifying risks and drawing up plans to minimize their effect on a project.
- A risk is a probability that some adverse circumstance will occur.

Project risks affect schedule or resources.

Product risks affect the quality or performance of the software being developed.

Business risks affect the organisation developing or procuring the software.

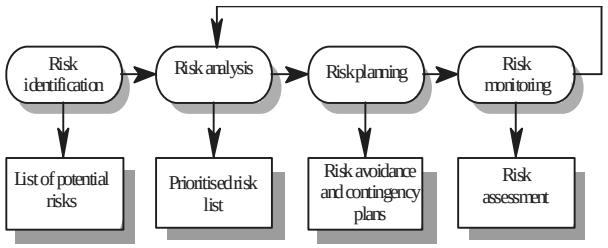
(Taxonomy based on Effect)

Software Risks

Risk	Risk type	Description
Staff turnover	Project	Experienced staff will leave the project before it is finished.
Management change	Project	There will be a change of organisational management with different priorities.
Hardware unavailability	Project	Hardware which is essential for the project will not be delivered on schedule.
Requirements change	Project and product	There will be a larger number of changes to the requirements than anticipated.
Specification delays	Project and product	Specifications of essential interfaces are not available on schedule
Size underestimate	Project and product	The size of the system has been underestimated.
CASE tool under-performance	Product	CASE tools which support the project do not perform as anticipated
Technology change	Business	The underlying technology on which the system is built is superseded by new technology.
Product competition	Business	A competitive product is marketed before the system is completed.

The Risk Management Process

- Risk identification : identify project, product and business risks
- Risk analysis : assess the likelihood and consequences of these risks
- Risk planning : draw up plans to avoid or minimise the effects of the risk
- Risk monitoring : monitor the risks throughout the project



Risk Identification

- Technology risks
- People risks
- Organisational risks
- Requirements risks
- Estimation risks

(Taxonomy based on *Source*)

Risks and Risk Types

Risk type	Possible risks
Technology	The database used in the system cannot process as many transactions per second as expected. Software components which should be reused contain defects which limit their functionality.
People	It is impossible to recruit staff with the skills required. Key staff are ill and unavailable at critical times. Required training for staff is not available.
Organisational	The organisation is restructured so that different management are responsible for the project. Organisational financial problems force reductions in the project budget.
Tools	The code generated by CASE tools is inefficient. CASE tools cannot be integrated.
Requirements	Changes to requirements which require major design rework are proposed. Customers fail to understand the impact of requirements changes.
Estimation	The time required to develop the software is underestimated. The rate of defect repair is underestimated. The size of the software is underestimated.

Risk Analysis

- Assess probability and seriousness of each risk.
- Probability may be very low, low, moderate, high or very high.
- Risk effects might be catastrophic, serious, tolerable or insignificant.

Risk	Probability	Effects
Organisational financial problems force reductions in the project budget.	Low	Catastrophic
It is impossible to recruit staff with the skills required for the project.	High	Catastrophic
Key staff are ill at critical times in the project.	Moderate	Serious
Software components which should be reused contain defects which limit their functionality.	Moderate	Serious
Changes to requirements which require major design rework are proposed.	Moderate	Serious
The organisation is restructured so that different management are responsible for the project.	High	Serious
The database used in the system cannot process as many transactions per second as expected.	Moderate	Serious
The time required to develop the software is underestimated.	High	Serious
CASE tools cannot be integrated.	High	Tolerable
Customers fail to understand the impact of requirements changes.	Moderate	Tolerable
Required training for staff is not available.	Moderate	Tolerable
The rate of defect repair is underestimated.	Moderate	Tolerable
The size of the software is underestimated.	High	Tolerable
The code generated by CASE tools is inefficient.	Moderate	Insignificant

Risk Planning

Consider each risk and develop a strategy to manage that risk. Avoidance strategies : the probability that the risk will arise is reduced.

Minimisation strategies : the impact of the risk on the project or product is reduced.

Contingency plans : if the risk arises, contingency plans are plans to deal with that risk.

Risk Management Strategies

Risk	Strategy
Organisational financial problems	Prepare a briefing document for senior management showing how the project is making a very important contribution to the goals of the business.
Recruitment problems	Alert customer of potential difficulties and the possibility of delays, investigate buying-in components.
Staff illness	Reorganise team so that there is more overlap of work and people therefore understand each other's jobs.
Defective components	Replace potentially defective components with bought-in components of known reliability.
Requirements changes	Derive traceability information to assess requirements change impact, maximise information hiding in the design.
Organisational restructuring	Prepare a briefing document for senior management showing how the project is making a very important contribution to the goals of the business.
Database performance	Investigate the possibility of buying a higher-performance database.
Underestimated development time	Investigate buying in components, investigate use of a program generator.

Risk Monitoring

- Assess each identified risk regularly to decide whether or not it is becoming less or more probable.
- Also assess whether the effects of the risk have changed.
- Each key risk should be discussed at management progress meetings.

Risk Factors

Risk	Strategy
Organisational financial problems	Prepare a briefing document for senior management showing how the project is making a very important contribution to the goals of the business.
Recruitment problems	Alert customer of potential difficulties and the possibility of delays, investigate buying-in components.
Staff illness	Reorganise team so that there is more overlap of work and people therefore understand each other's jobs.
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Database performance	Investigate the possibility of buying a higher-performance database.
Underestimated development time	Investigate buying in components, investigate use of a program generator.

Key Points

- Good project management is essential for project success.
- The intangible nature of software causes problems for management.
- Managers have diverse roles, but their most significant activities are planning, estimating, and scheduling.
- Planning and estimating are iterative processes, which continue throughout the course of a project.
- A project milestone is a predictable state where some formal report of progress is presented to management.
- Risks may be project risks, product risks or business risks.
- Risk management is concerned with identifying risks, which may affect the project, and planning to ensure that these risks do not develop into major threats.

Activitiy

Explain why the intangibility of software systems poses special problems for software project management.

Activitiy

Explain why the best programmers do not always make the best software managers.

Activity

Explain why the process of project planning is an iterative one and why a plan; must be continually reviewed during a software project.

Activity

Briefly explain the purpose of each of the sections in a software project plan.

Activity

What is the critical distinction between a milestone and a deliverable?

Activity

Following figure sets out a number of activities, durations and dependencies. Draw an activity chart and a bar chart showing the project schedule.

Task	Duration	Dependencies
T1	10	
T2	15	T1
T3	10	T1, T2
T4	20	
T5	10	
T6	15	T3, T4
T7	20	T3
T8	35	T7
T9	15	T6
T10	5	T5, T9
T11	10	T9
T12	20	T10
T13	35	T3, T4
T14	10	T8, T9
T15	20	T12, T14
T16	10	T15

Activity

You are asked by your manager to deliver software to a schedule, which you know can only be met, by asking your project team to work unpaid overtime. All team members have young children. Discuss whether you should accept this demand form your manager or whether you should persuade your team to give their time to the organization rather than their families. What factors might be significant in your decision?

Activity

As a programmer, you are offered promotion to project management but you feel that you can make a more effective contribution in a technical rather than a managerial role. Discuss whether you should accept the promotion.

Notes:

LESSON 6 AND 7:
SOFTWARE REQUIREMENTS

Objectives

- To introduce the concepts of abstract "user" and more detailed "system" requirements
- To describe functional and non-functional requirements
- To explain two techniques for describing system requirements: structured NL and PDLs
- To suggest how software requirements may be organized in a requirements document

Topics Covered

- Functional and non-functional requirements
- User requirements
- System requirements
- The software requirements document

Requirements Engineering

- The process of eliciting, analysing, documenting, and validating the services required of a system and the constraints under which it will operate and be developed.
- Descriptions of these services and constraints are the requirements for the system.
- Requirements may be high-level and abstract, or detailed and mathematical
- The hardest single part of building a software system is deciding precisely what to build. No other part of the conceptual work is as difficult… No other part of the work so cripples the resulting system if done wrong. No other part is more difficult to rectify later.

  – Fred Brooks, "No Silver Bullet…"

Why is Requirements Engineering So Hard?

- Difficulty of anticipation
- Unknown or conflicting requirements / priorities
- Conflicts between users and procurers
- Fragmented nature of requirements
- Complexity / number of distinct requirements
- Some analogies:

Working a dynamically changing jigsaw puzzle

Blind men describing an elephant

Different medical specialists describing an ill patient

Types of Requirements

- Requirements range from being high-level and abstract to detailed and mathematical.
- This is inevitable as requirements may serve multiple uses.

May be the basis for a bid for a contract – must be open to interpretation

May be the basis for the contract itself — must be defined in detail

May be the basis for design and implementation – must bridge requirements engineering and design activities

- User requirements : statements in natural language plus diagrams of system services and constraints. Written primarily for customers.
- System requirements : structured document setting out detailed descriptions of services and constraints precisely. May serve as a contract between client and developer.
- Software design specification : implementation oriented abstract description of software design, which may utilize formal (mathematical) notations. Written for developers.

User and System Requirements

1. The software must provice a means of representing and accessing external files created by other tools.

1. The user should be provided with facilities to define the type of external files.

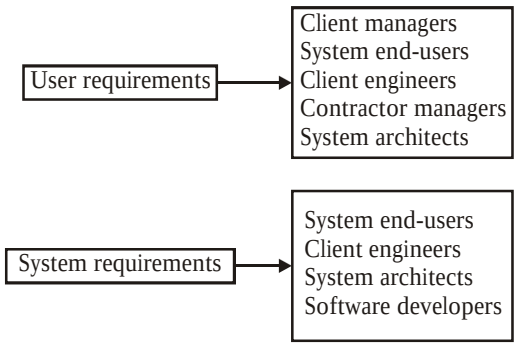
2. Each external file type may have an associated tool which may be applied to the file.

3. Each external file type may be represented as a specific icon on the user's display.

4. Facilities should be provided for the icon representing an external file type to be defined by the user.

5. When a user selects an icon representing an external file the effect of that selection is to apply the tool associated with the type of the external file to the file represented by the selected icon.

Requirements Readers



Functional and Non-functional Requirements

- Functional requirements : services the system should provide, how it should react to particular inputs, or how it should behave in particular situations.
- Non-functional requirements : constraints on services or functions (e.g., response time) or constraints on development process (e.g., use of a particular CASE toolset).
- Domain requirements : functional or non-functional requirements derived from application domain (e.g., legal requirements or physical laws

Examples of Functional Requirements

- The user shall be able to search either all of the initial set of databases or select a subset from it.
- The system shall provide appropriate viewers for the user to read documents in the document store.
- Every order shall be allocated a unique identifier (ORDER_ID), which the user shall be able to copy to the account's permanent storage area

Requirements Imprecision

- Problems arise when requirements are not precisely stated.
- Ambiguous requirements may be interpreted in different ways.
- Consider the term "appropriate viewers"

User intention : special purpose viewer for each different document type

Developer interpretation : provide a text viewer that shows the contents of the documents

Requirements Completeness and Consistency

- In principle, a requirements specification should be both complete and consistent.

Complete : all required services and constraints are defined.

Consistent : no conflicts or contradictions in the requirements.

- In practice, this is nearly impossible.

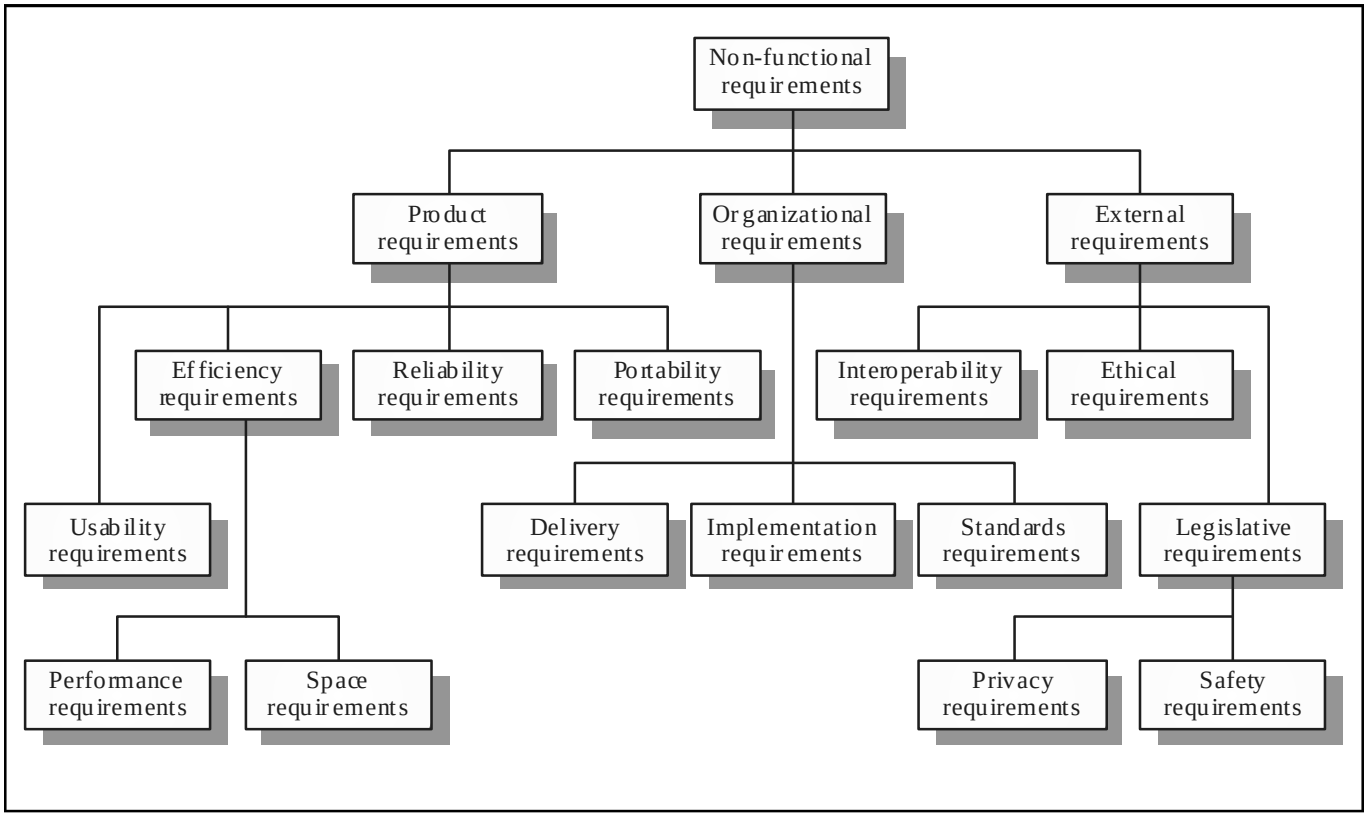
Non-functional Requirements

- Define system attributes (e.g., reliability, response time) and constraints (e.g., MTTF e•5K transactions, response time d•2 seconds).
- Attributes are often emergent system properties : i.e., only observable when the entire system is operational.
- Process constraints may mandate a particular CASE system, programming language, or development method.
- Non-functional requirements may be more critical than functional requirements. If not met, the system may be useless.

Non-functional Classifications

- Product requirements : specify product behaviour
- Organizational requirements : derived from policies / procedures in customer's or developer's organization (e.g., process constraints)
- External requirements : derived from factors external to the product and its development process (e.g., interoperability requirements, legislative requirements)

Non-functional Classifications



Examples

- Product requirement: 4.C.8 it shall be possible for all necessary communication between the APSE and the user to be expressed in the standard Ada character set.
- Organisational requirement: 9.3.2 the system development process and deliverable documents shall conform to the process and deliverables defined in XYZCo-SP-STAN-95.
- External requirement: 7.6.5 the system shall not disclose any personal information about customers apart from their name and reference number to the operators of the system.

Goals Versus Requirements

- General goals such as "system should be user friendly" or "system should have fast response time" are not verifiable.
- Goals should be translated into quantitative requirements that can be objectively tested.

Examples

- A system goal: The system should be easy to use by experienced controllers and should be organized in such a way that user errors are minimized.
- A verifiable non-functional requirement: Experienced controllers shall be able to use all the system functions after a total of two hours training. After this training, the average number of errors made by experienced users shall not exceed two per day.

Requirements Measures

Property	**Measure**
Speed	Processed transactions/second User/Event response time Screen refresh time
Size	K Bytes Number of RAM chips
Ease of use	Training time Number of help frames
Reliability	Mean time to failure Probability of unavailability Rate of failure occurrence Availability
Robustness	Time to restart after failure Percentage of events causing failure Probability of data corruption on failure
Portability	Percentage of target dependent statements Number of target systems

Requirement Interactions

- Competing / conflicting requirements are common with complex systems.
- Spacecraft system example:

To minimize weight, the number of chips in the unit should be minimized.

To minimize power consumption, low-power chips should be used.

But using low-power chips means that more chips have to be used. Which is the most critical requirement?

- For this reason, preferred points in the solution space should be identified.

Domain Requirements

- Derived from the application domain rather than user needs.
- May be new functional requirements or constraints on existing requirements.
- If domain requirements are not satisfied, the system may be unworkable.

Library System Domain Requirements

- There shall be a standard user interface to all databases, which shall be based on the Z39.50 standard.
- Because of copyright restrictions, some documents must be deleted immediately on arrival. Depending on the user's requirements, these documents will either be printed locally on the system server for manually forwarding to the user or routed to a network printer.

Train Protection System Domain Requirement

- The deceleration of the train shall be computed as:

Dtrain = Dcontrol + Dgradient

where Dgradient is 9.81m/s2 * compensated gradient/alpha and where the values of 9.81m/s2 /alpha are known for different types of train.

Domain Requirements Problems

- Understandability : requirements are expressed in the language of the application domain and may not be understood by software engineers.
- Implicitness : domain experts may not communicate such requirements because they are so obvious (to the experts).

User Requirements "Shoulds"

- Should be understandable by system users who don't have detailed technical knowledge.
- Should only specify external system behaviour.
- Should be written using natural language, forms, and simple intuitive diagrams.

Some Potential Problems With Using Natural Language

- Lack of clarity : expressing requirements precisely is difficult without making the document wordy and difficult to read.
- Requirements confusion : functions, constraints, goals, and design info may not be clearly distinguished.
- Requirements amalgamation : several different requirements may be lumped together.

Guidelines For Writing User Requirements

- Adopt a standard format and use it for all requirements.
- Use language in a consistent way. E.g., use shall for mandatory requirements, should for desirable requirements.
- Use text highlighting to identify key parts of the requirement.
- Avoid the use of computer jargon.

System Requirements

- More detailed descriptions of user requirements
- May serve as the basis for a contract
- Starting point for system design & implementation
- May utilize different system models such as object or dataflow

System Requirements And Design Information

- In principle, system requirements should state ***what*** the system should do, and ***not how*** it should be designed.
- In practice, however, some design info may be incorporated, since:

Sub-systems may be defined to help structure the requirements.

Interoperability requirements may constrain the design.

Use of a specific design model may be a requirement

More Potential Problems With Using Natural Language

- Ambiguity : the readers and writers of a requirement must interpret the same words in the same way. NL is naturally ambiguous so this is very difficult.
- Over-flexibility : the same requirement may be stated in a number of different ways. The reader must determine when requirements are the same and when they are different.
- Lacks of modularisation : NL structures are inadequate to structure system requirements sufficiently.

Alternatives to NL Specification

Notation	Description
Structured natural language	This approach depends on defining standard forms or templates to express the requirements specification.
Design description languages	This approach uses a language like a programming language but with more abstract features to specify the requirements by defining an operational model of the system.
Graphical notations	A graphical language, supplemented by text annotations is used to define the functional requirements for the system. An early example of such a graphical language was SADT (Ross, 1977; Schoman and Ross, 1977). More recently, use-case descriptions (Jacobsen, Christerson et al., 1993) have been used. I discuss these in the following chapter.
Mathematical specifications	These are notations based on mathematical concepts such as finite-state machines or sets. These unambiguous specifications reduce the arguments between customer and contractor about system functionality. However, most customers don't understand formal specifications and are reluctant to accept it as a system contract. I discuss formal specification in Chapter 9.

Program Description Languages (PDLs)

- Requirements are specified operationally using pseudo-code.
- Shows what is required by illustrating how the requirements could be satisfied.
- Especially useful when specifying a process that involves an ordered sequence of actions, or when describing hardware and software interfaces.

Part of an ATM Specification

```
class ATM {
  // declarations here
  public static void main (String args[]) throws InvalidCard {
      try {
          thisCard.read () ;  // may throw InvalidCard exception
          pin = KeyPad.readPin () ; attempts = 1 ;
          while ( !thisCard.pin.equals (pin) & attempts < 4 )
              {     pin = KeyPad.readPin () ;  attempts = attempts + 1 ;
              }
              if (!thisCard.pin.equals (pin))
                  throw new InvalidCard ("Bad PIN");
          thisBalance = thisCard.getBalance () ;
          do {  Screen.prompt (" Please select a service ") ;
              service = Screen.touchKey () ;
              switch (service) {
                  case Services.withdrawalWithReceipt:
                          receiptRequired = true ;
```

PDL Disadvantages

- PDL may not be sufficiently expressive to illustrate requirements in a concise an understandable way.
- Notation is only understandable to people with programming language knowledge.
- The specification may be taken as a design prescription rather than a model to facilitate requirements understanding.

Interface Specification

- Used to specify operating interfaces with other systems.

Procedural interfaces

Data structures that are exchanged

Data representations

- Also used to specify functional behaviour.
- Formal notations are effective for interface specification – e.g., pre- and post-conditions

PDL Interface Description

Example: Interface and Operational Specifications of a Function

```
interface PrintServer {

// defines an abstract printer server
// requires:interface Printer, interface PrintDoc
// provides: initialize, print, displayPrintQueue, cancelPrintJob, switchPrinter

   void initialize ( Printer p ) ;
   void print ( Printer p, PrintDoc d ) ;
   void displayPrintQueue ( Printer p ) ;
   void cancelPrintJob (Printer p, PrintDoc d) ;
   void switchPrinter (Printer p1, Printer p2, PrintDoc d) ;
} //PrintServer
```

Function: Set BIG to the largest value in array A [1.. N]

Interface Specification

Pre-condition: $N \geq 1$

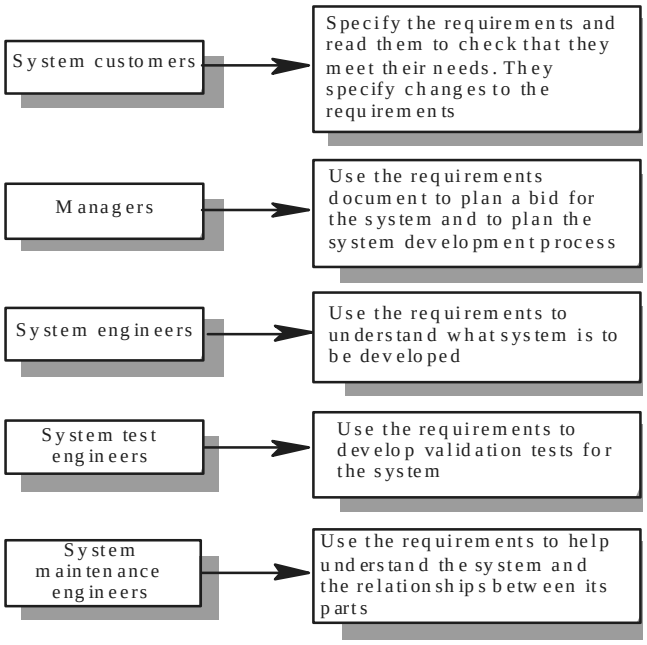
Post-condition: there exists an i in [1,N] such that BIG=A [i] & for every in [1,N], BIG $\geq$ A [j] & A is unchanged

```
Operational Specification
        if N e•1 then do
                BIG: = A [1]
                for i = 2 to N do
        if A [i] > BIG then BIG: = A [i] end if
        end for
end if
```

The Requirements Document (SRS)

- The official statement of what is required of the system developers.
- Should include both user and system requirements.
- NOT a design document. As much as possible, it should set out WHAT the system should do rather than HOW it should do it.

Users of a Requirements Document


System customers
Specify the requirements and read them to check that they meet their needs. They specify changes to the requirements
Managers
Use the requirements document to plan a bid for the system and to plan the system development process
System engineers
Use the requirements to understand what system is to be developed
System test engineers
Use the requirements to develop validation tests for the system
System maintenance engineers
Use the requirements to help understand the system and the relationships between its parts

Requirements Document Requirements

- Specify external system behaviour
- Specify implementation *constraints*
- Easy to change (!)
- Serve as reference tool for maintenance
- Record forethought about the life cycle of the system i.e. predict changes
- Characterise responses to unexpected events

IEEE Requirements Standard

- Introduction
- General description
- Specific requirements
- Appendices
- Index
- This is a generic structure that must be instantiated for specific systems

Requirements Document Structure

- Preface (readers, version, change history)
- Introduction
- Glossary
- User requirements definition
- System requirements specification
- System models
- System evolution
- Appendices
- Index

Key Points

- Requirements set out what the system should do and define constraints on its operation and implementation.
- Functional requirements set out services the system should provide
- Non-functional requirements constrain the system being developed or the development process
- User requirements are high-level statements of what the system should do
- User requirements should be written in natural language, tables and diagrams.
- System requirements are intended to communicate the functions that the system should provide.
- System requirements may be written in structured natural language, a PDL or in a formal language.
- A software requirements document (SRS) is the agreed statement of system requirements

Activity

Discuss the problems of using natural language for defining user and system requirements and show, using small examples, how structuring natural language into forms can help avoid some of these difficulties.

Activity

Discuss ambiguities or omissions in the following statements of requirements for part of a ticket issuing system.

An automated ticket issuing system sells rail tickets. Users select their destination, and input a credit card and a personal identification number. The rail ticket is issued and their credit card account charged with its cost. When the user presses the start button, a menu display of potential destinations is activated along with a message to the user to select a destination. Once a destination has been selected, users are requested to input their credit card. Its validity is checked and the user is then requested to input a personal identifier. When the credit transaction has been validated, the ticket is issued.

Activity

Rewrite the above description using the structured approach described in this chapter. Resolve the identified ambiguities in some appropriate way.

Activity

Write system requirements for the above system using a Java based notation. You may make any reasonable assumptions about the system. Pay particular attention to specifying user errors.

Activity

Using the technique suggested here where natural language is presented in a standard way, write plausible user requirements for the following functions:

- An unattended petrol (gas) pump system that includes a credit card reader. The customer swipes the card through the reader then specifies the amount of fuel required. The fuel is delivered and the customer's account debited.
- The cash dispensing functioning a bank auto teller machine.
- The spell checking and correcting functioning a word processor.

Activity

Describe three different types of non-functional requirement, which may be placed on a system. Give examples of each of these types of requirement.

Activity

Write a set of non-functional requirements for the ticket issuing system described above, setting out its expected reliability and its response time.

Activity

You have taken a job with a software user who has contracted your previous employer to develop a system for them. You discover that your compan7y's interpretation of the requirements is different form the interpretation taken by your previous employer. Discuss what you should do in such a situation. You know that the costs to your current employer will increases in the ambiguities are not resolved. You have also a responsibility of confidentiality to your previous employer.

LESSON 8 AND 9:
REQUIREMENTS ENGINEERING PROCESS

Objectives

- To describe the principal requirements engineering activities
- To introduce techniques for requirements elicitation and analysis
- To describe requirements validation
- To discuss the role of requirements management in support of other requirements engineering processes

Topics Covered

- Feasibility studies
- Requirements elicitation and analysis
- Requirements validation
- Requirements management

Requirements Engineering Processes

- The processes used for RE vary widely depending on the application domain, the people involved and the organization developing the requirements.
- However, there are a number of generic activities common to most processes:

Feasibility study

Requirements elicitation and analysis

Requirements specification

Requirements validation

Feasibility Study

- Determines whether or not the proposed undertaking is worthwhile.
- Aims to answer three basic questions:

Would the system contribute to overall organizational objectives?

Could the system be engineered using current technology and within budget?

Could the system be integrated with other systems already in use?

Feasibility Study Issues

- How would the organization cope if the system weren't implemented?
- What are the current process problems and how would the system help with these?
- What will the integration problems be?
- Is new technology needed? New skills?
- What must be supported by the system, and what need not be supported?

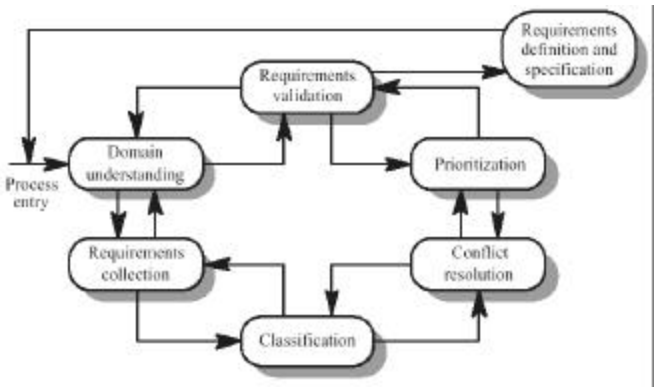
Elicitation and Analysis

- Involves working with customers to learn about the application domain, the services needed and the system's operational constraints.
- May also involve end-users, managers, maintenance personnel, domain experts, trade unions, etc. (That is, any stakeholders.)

Problems of Elicitation and Analysis

- Getting all, and only, the right people involved.
- Stakeholders often don't know what they really want ("I'll know when I see it").
- Stakeholders express requirements in their own terms.
- Stakeholders may have conflicting requirements.
- Requirements change during the analysis process. New stakeholders may emerge and the business environment may evolve.
- Organizational and political factors may influence the system requirements.

The Elicitation and Analysis Process



Viewpoint-oriented Elicitation

- Stakeholders represent different ways of looking at a problem (viewpoints)
- A multi-perspective analysis is important, as there is no single correct way to analyse system requirements.
- Provides a natural way to structure the elicitation process.

Types of Viewpoints

- Data sources or sinks : viewpoints are responsible for producing or consuming data. Analysis involves checking that assumptions about sources and sinks are valid.
- Representation frameworks : viewpoints represented by different system models (i.e., dataflow, ER, finite state

machine, etc.). Each model yields different insights into the system.

- Receivers of services : viewpoints are external to the system and receive services from it. Natural to think of end-users as external service receivers.

Method-based RE

· "Structured methods" to elicit, analyse, and document requirements.

- Examples include:

Ross' Structured Analysis (SA),

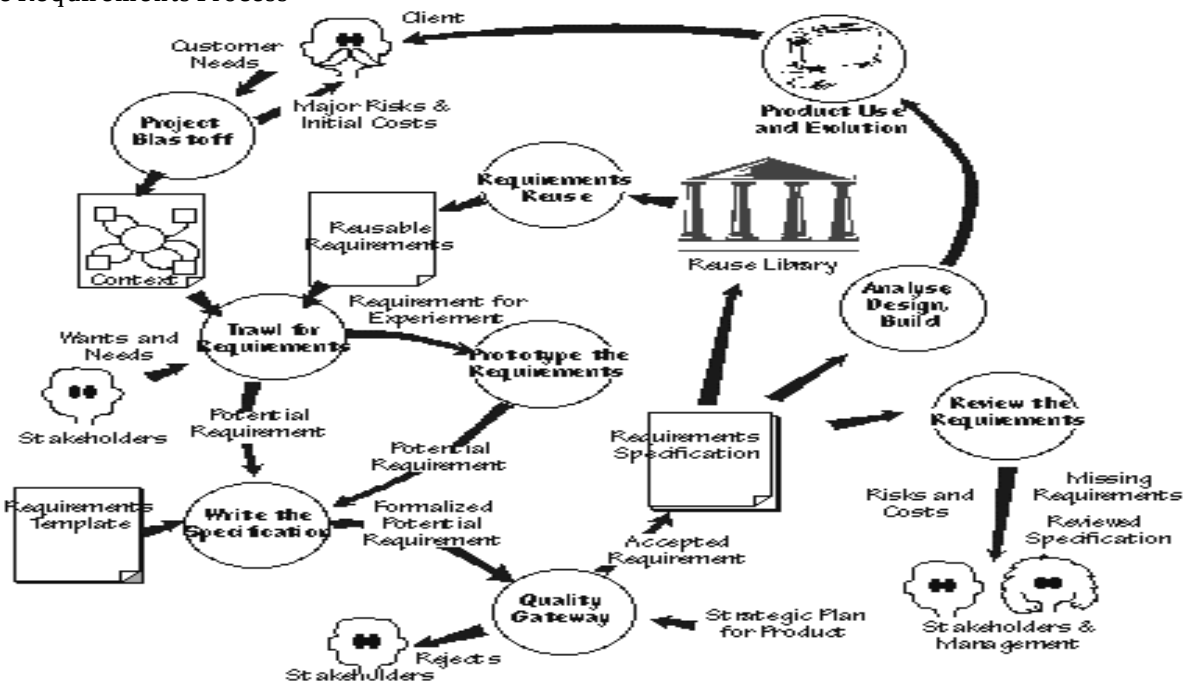
Volere Requirements Process (www.volere.co.uk)

Knowledge Acquisition and Sharing for Requirement Engineering (KARE) (www.kare.org),

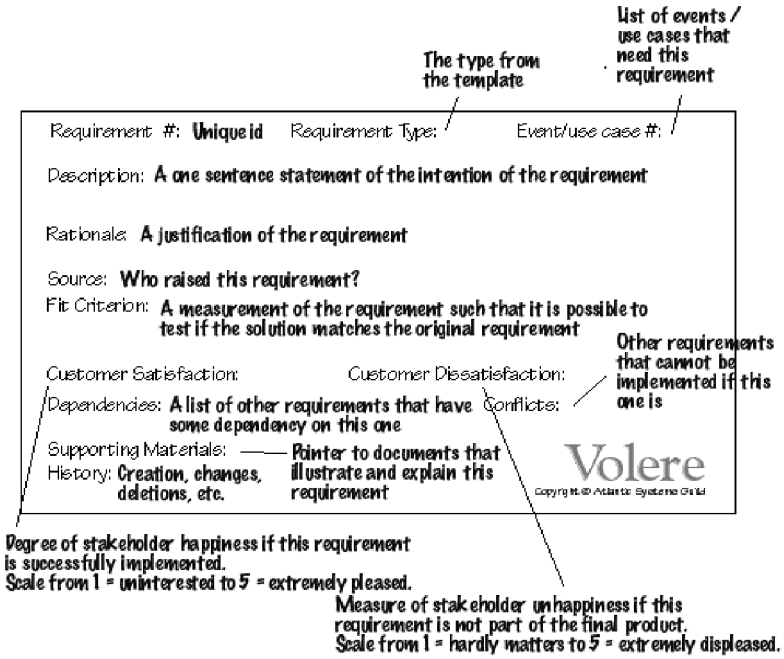
Somerville's Viewpoint-Oriented Requirements Definition (VORD), and

The baut's *Scenario-Based Requirements Engineering (SBRE)*

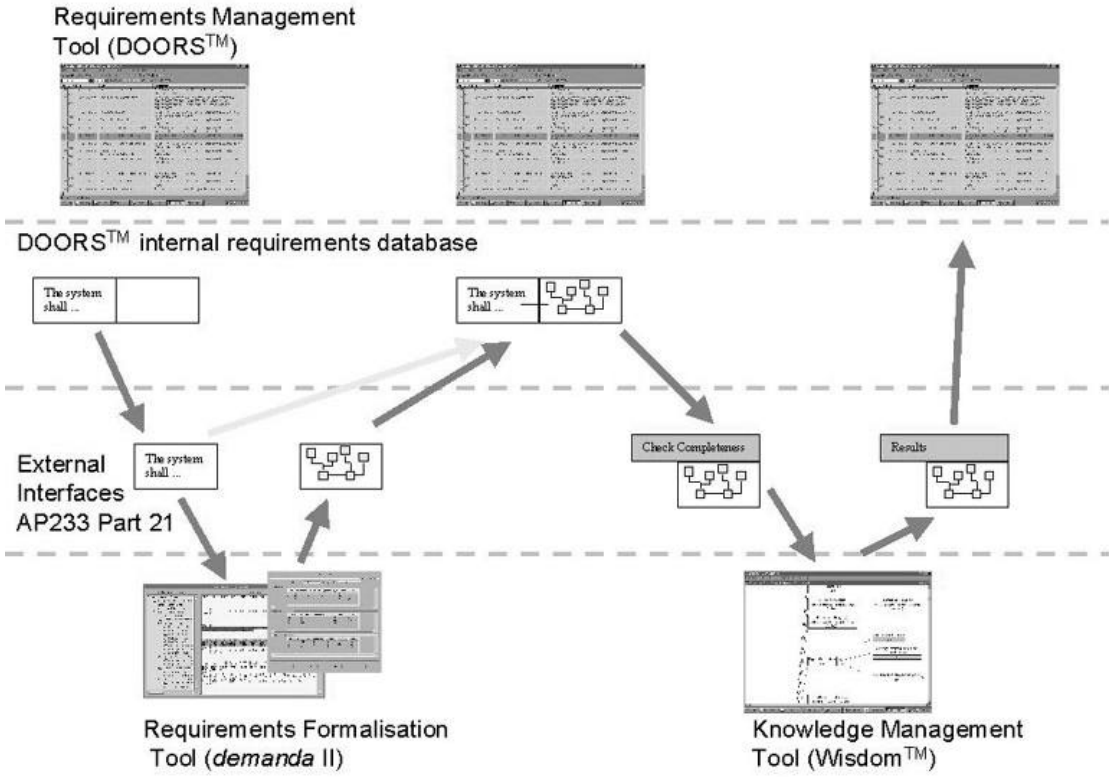
Volere Requirements Process



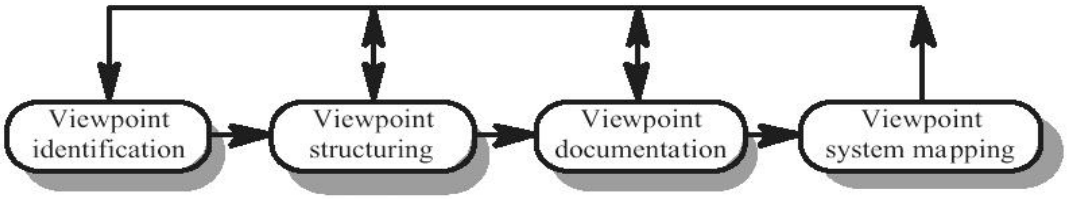
Volere Requirement Shell


List of events / use cases that need this requirement
The type from the template
Requirement #: Unique id
Requirement Type:
Event/use case #:
Description: A one sentence statement of the intention of the requirement
Rationale: A justification of the requirement
Source: Who raised this requirement?
Fit Criterion: A measurement of the requirement such that it is possible to test if the solution matches the original requirement
Customer Satisfaction:
Customer Dissatisfaction:
Other requirements that cannot be implemented if this one is
Dependencies: A list of other requirements that have some dependency on this one
Conflicts:
Supporting Materials:
Pointer to documents that illustrate and explain this requirement
History: Creation, changes, deletions, etc.
Volere
Degree of stakeholder happiness if this requirement is successfully implemented. Scale from 1 = uninterested to 5 = extremely pleased.
Measure of stakeholder unhappiness if this requirement is not part of the final product. Scale from 1 = hardly matters to 5 = extremely displeased.

KARE Workbench Architecture



Somerville's VORD Method



VORD Standard Forms

Viewpoint template

Reference:	The viewpoint name.
Attributes:	Attributes providing viewpoint information.
Events:	A reference to a set of event scenarios describing how the system reacts to viewpoint events.
Services	A reference to a set of service descriptions.
Sub-VPs:	The names of sub-viewpoints.

Service template

Reference:	The service name.
Rationale:	Reason why the service is provided.
Specification:	Reference to a list of service specifications. These may be expressed in different notations.
Viewpoints:	List of viewpoint names receiving the service.
Non-functional requirements:	Reference to a set of non-functional requirements which constrain the service.
Provider:	Reference to a list of system objects which provide the service.

Scenarios

- Depict examples or scripts of possible system behaviour.
- People often relate to these more readily than to abstract statements of requirements.
- Particularly useful in dealing with fragmentary, incomplete, or conflicting requirements.

Scenario Descriptions

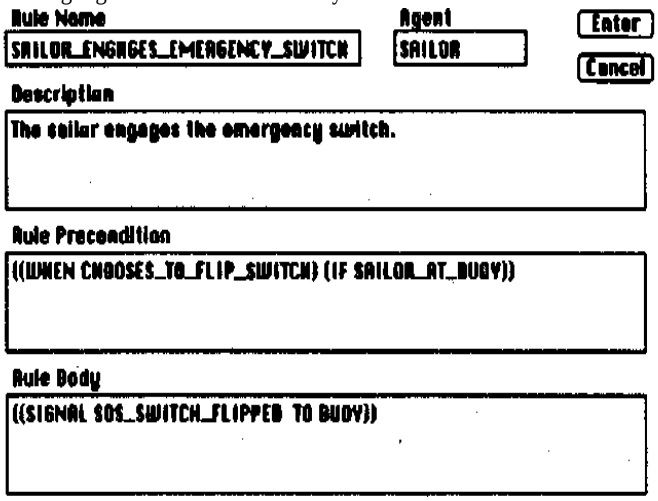
- System state at the beginning of the scenario.
- Sequence of events for a specific case of some generic task the system is required to accomplish.
- Any relevant concurrent activities.
- System state at the completion of the scenario.

A Simple Scenario

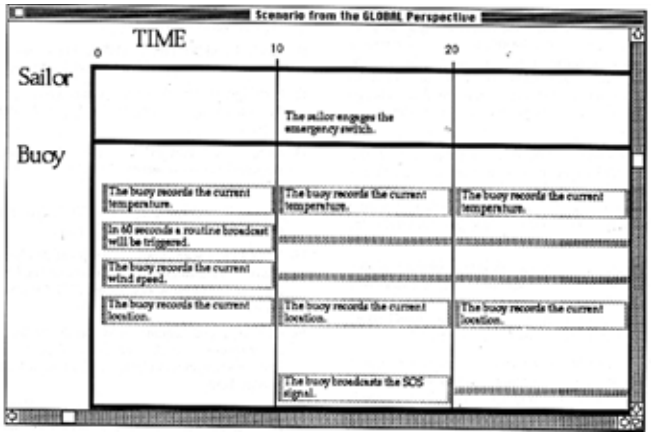
- t0: The user enters values for input array A. The values are [1, 23, -4, 7, 19]. The value of output variable BIG remains 'undefined'.
- t1: The user executes program MAX.
- t2: The value of variable BIG is 23 and the values of A are [1, 23, -4, 7, 19].

Scenario-Based Requirements Engineering (SBRE)

- Marcel support environment allows rapid construction of an operational specification of the desired system and its environment.
- Based on a forward chaining rule-based language.
- An interpreter executes the specification to produce natural language based scenarios of system behavior.



SBRE Scenario Generation


Scenario from the GLOBAL Perspective
TIME
0
10
20
Sailor
Buoy
The sailor engages the emergency switch.
The buoy records the current temperature.
The buoy records the current temperature.
The buoy records the current temperature.
In 60 seconds a routine broadcast will be triggered.
The buoy records the current wind speed.
The buoy records the current location.
The buoy records the current location.
The buoy records the current location.
The buoy broadcasts the SOS signal.

Scenario Representation in VORD

- VORD supports the graphical description of multi-threaded "event scenarios" to document system behaviour:

Data provided and delivered

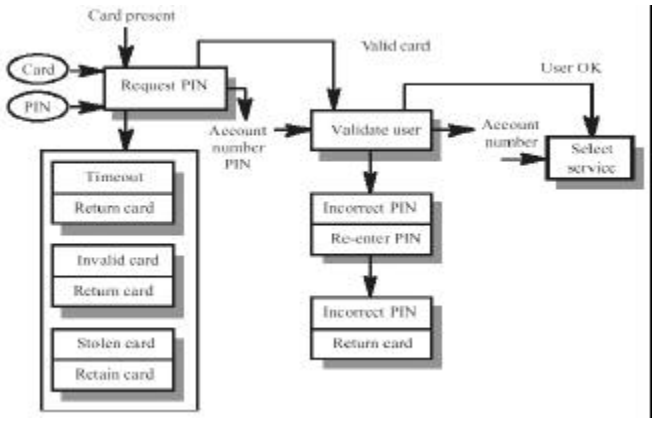
Control information

Exception processing

The next expected event

- Multi-threading supports description of exceptions.

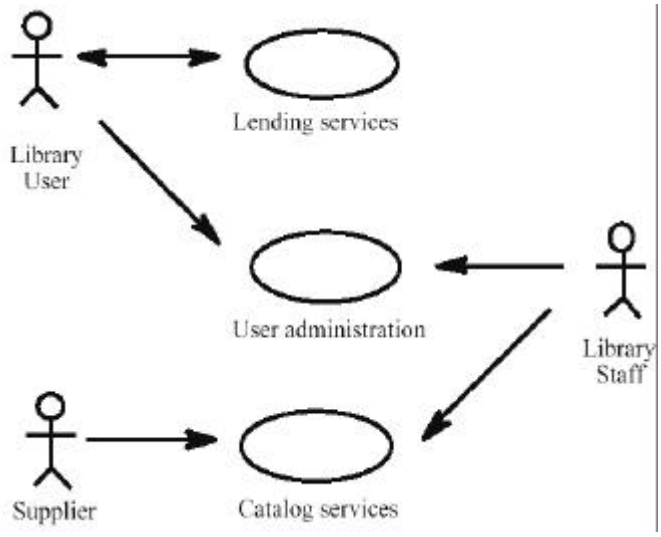
Scenario for a "Start Transaction" Event



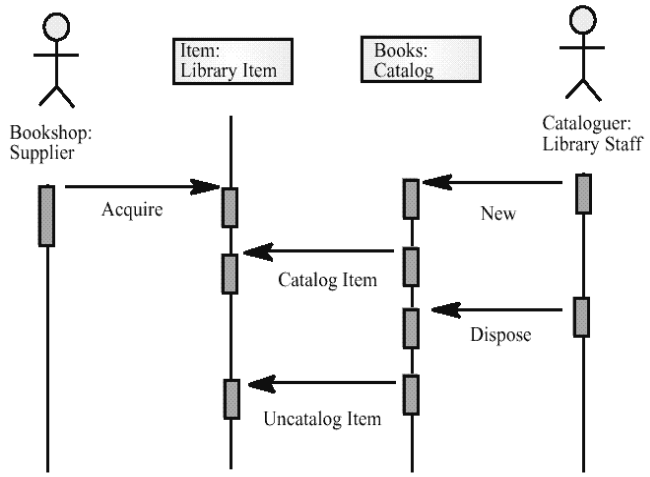
UML Use-cases and Sequence Diagrams

- Use-cases are a graphical notation for representing abstract scenarios in the UML.
- They identify the actors in an interaction and describe the interaction itself.
- A set of use-cases should describe all types of interactions with the system.
- Sequence diagrams may be used to add detail to use-cases by showing the sequence of event processing.

Library Use-cases



Catalogue Management Sequence Diagram



Social and Organizational Factors

- All software systems are used in a social and organizational context. This can influence or even dominate the system requirements.
- Good analysts must be sensitive to these factors, but there is currently no systematic way to tackle their analysis.

Example

- Consider a system: which allows senior management to access information without going through middle managers.
- Managerial status: Senior managers may feel that they are too important to use a keyboard. This may limit the type of system interface used.
- Managerial responsibilities: Managers may have no uninterrupted time when they can learn to use the system
- Organizational resistance: Middle managers who will be made redundant may deliberately provide misleading or incomplete information so that the system will fail.

Ethnography

- A social scientists spends considerable time observing and analysing how people actually work.
- People do not have to explain or articulate what they do.
- Social and organizational factors of importance may be observed.
- Ethnographic studies have shown that work is usually richer and more complex than suggested by simple system models.

Focused Ethnography

- Developed during a project studying the air traffic control process.
- Combines ethnography with prototyping.
- Prototype development raises issues: which focus the ethnographic analysis.
- Problem with ethnography alone: it studies existing practices, which may not be relevant when a new system is put into place.

Requirements Validation

- Concerned with whether or not the requirements define a system that the customer really wants.
- Requirements error costs are high, so validation is very important. (Fixing a requirements error after delivery may cost up to 100 times that of fixing an error during implementation.)

Requirements Checking

- Validity: Does the system provide the functions which best support the customer's needs?
- Consistency: Are there any requirements conflicts?
- Completeness: Are all functions required by the customer included?
- Realism: Can the requirements be implemented given available budget and technology?
- Verifiability: Can the requirements be *tested?*

Requirements Validation Techniques

- Requirements reviews / inspections : systematic manual analysis of the requirements.
- Prototyping : using an executable model of the system to check requirements.
- Test-case generation : developing tests for requirements to check testability.
- Automated consistency analysis : checking the consistency of a structured requirements description.

Requirements Reviews / Inspections

- Regular reviews should be held while the requirements definition is being formulated.
- Both client and contractor staff should be involved in reviews. (Stakeholders)
- Reviews may be formal (with completed documents) or informal. Good communications between developers, customers and users can resolve problems at an early stage.

Review Check-list

- Verifiability: Is the requirement realistically testable?
- Comprehensibility: Is the requirement properly understood?
- Traceability: Is the origin of the requirement clearly stated?
- Adaptability: Can the requirement be changed with minimum impact on other requirements? (Especially when change is anticipated!)

Requirements Management

- Requirements management is the process of managing changing requirements during the requirements engineering process and system development.
- New requirements emerge during the process as business needs change and a better understanding of the system is developed.
- The priority of requirements from different viewpoints changes during the development process.
- The business and technical environment of the system changes during its development.

Enduring and Volatile Requirements

- Enduring requirements: Stable requirements derived from the core activity of the customer organization. E.g., a hospital will always have doctors, nurses, etc. May be derived from domain models.
- Volatile requirements: Requirements which change during development or when the system is in use. E.g., requirements derived from the latest health-care policy.

Classification of Requirements

- Mutable requirements : those that change due to changes in the system's environment.
- Emergent requirements : those that emerge as understanding of the system develops.
- Consequential requirements : those that result from the introduction of the system.
- Compatibility requirements : those that depend on other systems or organizational processes.

Requirements Management Planning

- During requirements management planning, you must decide on:
- Requirements identification : how requirements will be individually identified.
- A change management process : a process to be followed when analysing the impact and costs of a requirements change.
- Traceability policies : the amount of information about requirements relationships that is maintained.
- CASE tool support : the tool support required to help manage requirements change.

Traceability

- Traceability is concerned with the relationships between requirements, their sources, and the system design.
- Source traceability : links from requirements to stakeholders who proposed these requirements.
- Requirements traceability : links between dependent requirements.
- Design traceability : links from the requirements to the design.

CASE Tool Support

- Requirements storage : requirements should be managed in a secure, managed data store.
- Change management : the process of change management is a workflow process whose stages can be defined and information flow between the stages partially automated.
- Traceability management : automated discovery and documentation of relationships between requirements

Requirements Change Management

- Should apply to all proposed changes to the requirements.
- Principal stages:

Problem analysis : discuss identified requirements problem and propose specific change(s).

Change analysis and costing : assess effects of change on other requirements.

Change implementation : modify requirements document and others to reflect change.

Requirements Change Management

Key Points

- The requirements engineering process includes a feasibility study, elicitation and analysis, specification, and validation.
- Requirements analysis is an iterative process involving domain understanding, requirements collection, classification, structuring, prioritization and validation.
- Systems have multiple stakeholders with different viewpoints and requirements.
- Social and organization factors influence system requirements.
- Requirements validation is concerned with checks for validity, consistency, complete-ness, realism, and verifiability.
- Business, organizational, and technical changes inevitably lead to changing requirements.
- Requirements management involves careful planning and a change management process.

Activity

Suggest who might be stakeholders in a university student records system. Explain why it is almost inevitable that the requirements of different stakeholders will conflict in some ways.

Activity

A software system is to be developed to automate a library catalogue. This system will contain information about all the books in a library and will be usable by library staff and by book borrows and reasons the system should support catalogue browsing, querying, and should provide facilities allowing users to send messages to library staff reserving a book which is on loan. Identify the principal viewpoints, which might be taken into account in the specification of this system and show their relationships using a viewpoint hierarchy diagram.

Activity

For three of the viewpoints identified in the library cataloguing system, suggest services which might be provided to that viewpoint, data which the viewpoint might provide and events which control the delivery of these services.

Activity

Using your own knowledge of how an ATM is used, develop a set of use cases that could be used to derive the requirements for an ATM system.

Activity

Discuss an example of a type of system where social and political factors might strongly influence the system requirements. Explain why these factors are important in your example.

Activity

Who should be involved in a requirements review? Draw a process model showing how a requirements review might be organized.

Activity

Why do tractability matrices become difficult to mange when there are many system requirements? Design a requirements structuring mechanism, based on viewpoints, which might help reduce the scale of this problem.

Activity

When emergency changes have to be made to system software may have to be modified before changes to the requirements have been approved. Suggest a model of a process for making these modifications, which ensures that the requirements document and the system implementation do not become inconsistent.

Activity

Your company uses a standard analysis method which is normally applied in all requirements analyses. In your work, you find that this method cannot represent social factors, which are significant in the system you are analyzing. You point out to your manager who makes clear that the standard should be followed. Discuss what you should do in such a situations.

Notes:

LESSON 10 AND 11: SYSTEM MODELS

Abstract Descriptions of Systems Whose Requirements are Being Analysed

Objectives

- To explain why the context of a system should be modelled as part of the RE process
- To describe behavioural modelling, data modelling and object modelling
- To introduce some of the notations used in the Unified Modelling Language (UML)
- To show how CASE workbenches support system modelling

Topics Covered

- Context models
- Behavioural models
- Data models
- Object models
- CASE workbenches

System Modelling

- System modelling helps the analyst to understand the functionality of the system and models are used to communicate with customers
- Different models present the system from different perspectives

External perspective showing the system's context or environment

Behavioural perspective showing the behaviour of the system

Structural perspective showing the system or data architecture

Structured Methods

- Structured methods incorporate system modelling as an inherent part of the method
- Methods define a set of models, a process for deriving these models and rules and guidelines that should apply to the models
- CASE tools support system modelling as part of a structured method

Method Weaknesses

- They do not model non-functional system requirements
- They do not usually include information about whether a method is appropriate for a given problem
- The may produce too much documentation
- The system models are sometimes too detailed and difficult for users to understand

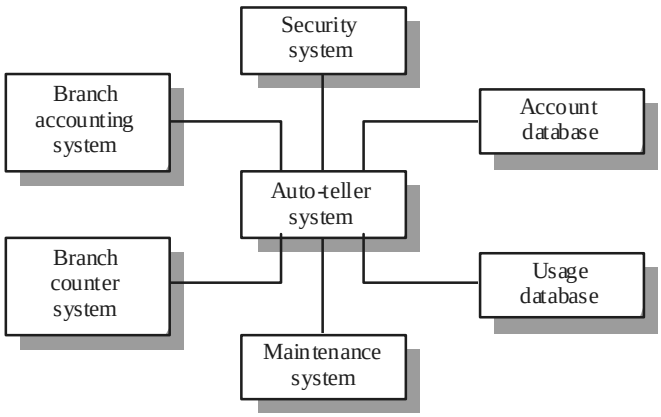
Model Types

- Data processing model showing how the data is processed at different stages
- Composition model showing how entities are composed of other entities
- Architectural model showing principal sub-systems
- Classification model showing how entities have common characteristics
- Stimulus/response model showing the system's reaction to events

Context Models

- Context models are used to illustrate the boundaries of a system
- Social and organisational concerns may affect the decision on where to position system boundaries
- Architectural models show the a system and its relationship with other systems

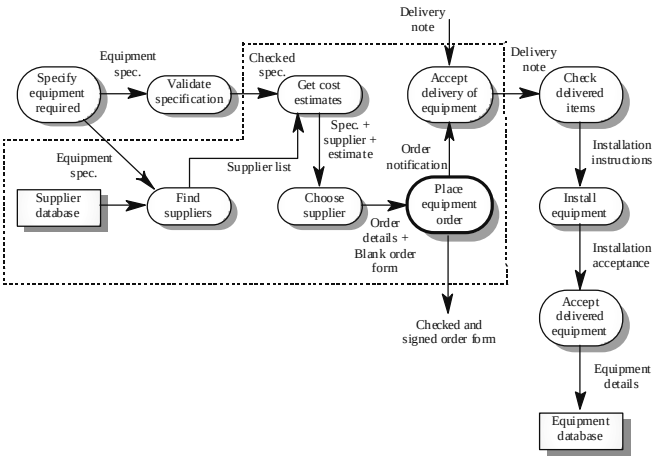
The Context of An ATM System



Process Models

- Process models show the overall process and the processes that are supported by the system
- Data flow models may be used to show the processes and the flow of information from one process to another

Equipment Procurement Process



Behavioural Models

- Behavioural models are used to describe the overall behaviour of a system
- Two types of behavioural model are shown here

Data-processing models that show how data is processed as it moves through the system

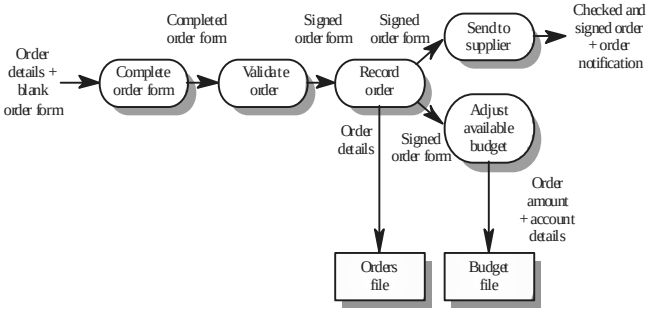
State machine models that show the systems response to events

- Both of these models are required for a description of the system's behaviour

Data-processing Models

- Data flow diagrams are used to model the system's data processing
- These show the processing steps as data flows through a system
- Intrinsic part of many analysis methods
- Simple and intuitive notation that customers can understand
- Show end-to-end processing of data

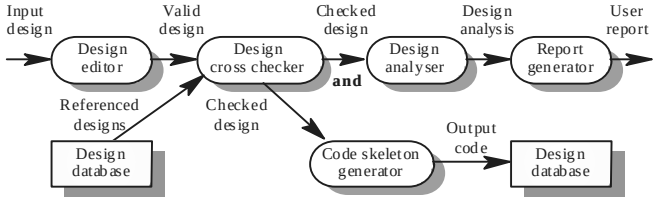
Order Processing DFD



Data Flow Diagrams

- DFDs model the system from a functional perspective
- Tracking and documenting how the data associated with a process is helpful to develop an overall understanding of the system
- Data flow diagrams may also be used in showing the data exchange between a system and other systems in its environment

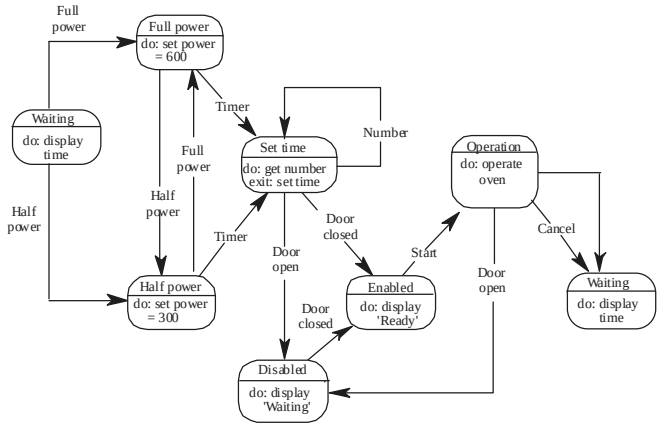
CASE Toolset DFD



State Machine Models

- These model the behaviour of the system in response to external and internal events
- They show the system's responses to stimuli so are often used for modelling real-time systems
- State machine models show system states as nodes and events as arcs between these nodes. When an event occurs, the system moves from one state to another
- State charts are an integral part of the UML

Microwave Oven Model



Microwave Oven State Description

State	Description
Waiting	The oven is waiting for input. The display shows the current time.
Half power	The oven power is set to 300 watts. The display shows 'Half power'.
Full power	The oven power is set to 600 watts. The display shows 'Full power'.
Set time	The cooking time is set to the user's input value. The display shows the cooking time selected and is updated as the time is set.
Disabled	Oven operation is disabled for safety. Interior oven light is on. Display shows 'Not ready'.
Enabled	Oven operation is enabled. Interior oven light is off. Display shows 'Ready to cook'.
Operation	Oven in operation. Interior oven light is on. Display shows the timer countdown. On completion of cooking, the buzzer is sounded for 5 seconds. Oven light is on. Display shows 'Cooking complete' while buzzer is sounding.

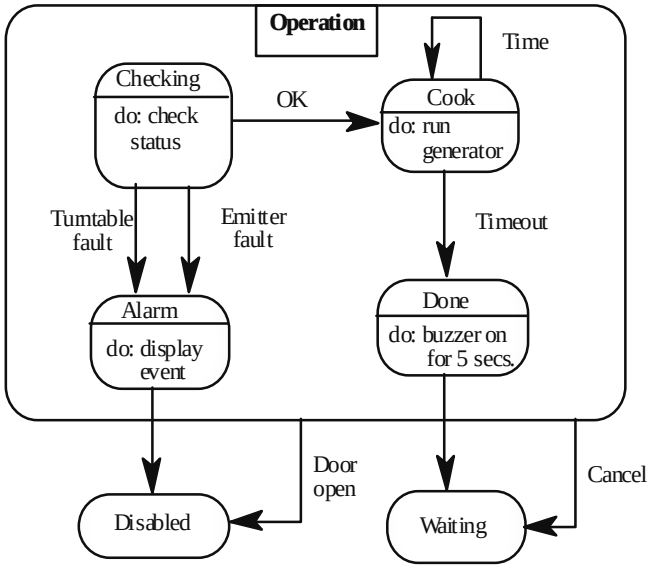
Microwave Oven Stimuli

Stimulus	Description
Half power	The user has pressed the half power button
Full power	The user has pressed the full power button
Timer	The user has pressed one of the timer buttons
Number	The user has pressed a numeric key
Door open	The oven door switch is not closed
Door closed	The oven door switch is closed
Start	The user has pressed the start button
Cancel	The user has pressed the cancel button

State Charts

- Allow the decomposition of a model into sub-models (see following slide)
- A brief description of the actions is included following the 'do' in each state
- Can be complemented by tables describing the states and the stimuli

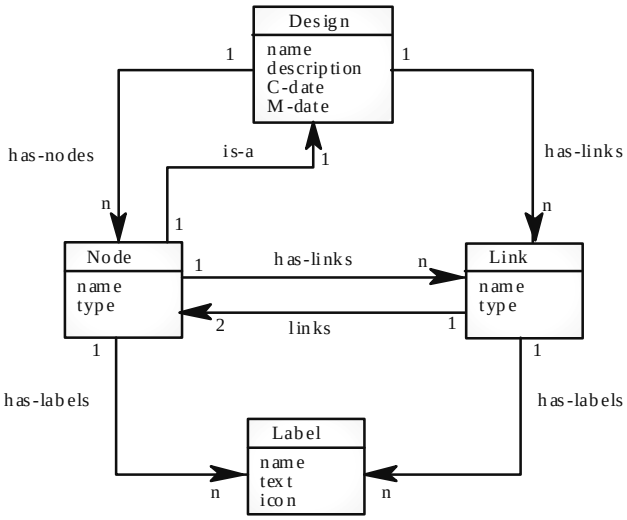
Microwave Oven Operation



Semantic Data Models

- Used to describe the logical structure of data processed by the system
- Entity-relation-attribute model sets out the entities in the system, the relationships between these entities and the entity attributes
- Widely used in database design. Can readily be implemented using relational databases
- No specific notation provided in the UML but objects and associations can be used

Software Design Semantic Model



Data Dictionaries

- Data dictionaries are lists of all of the names used in the system models. Descriptions of the entities, relationships and attributes are also included
- Advantages

Support name management and avoid duplication

Store of organisational knowledge linking analysis, design and implementation

- Many CASE workbenches support data dictionaries

Data Dictionary Entries

Name	Description	Type	Date
has-labels	1:N relation between entities of type Node or Link and entities of type Label.	Relation	5.10.1998
Label	Holds structured or unstructured information about nodes or links. Labels are represented by an icon (which can be a transparent box) and associated text.	Entity	8.12.1998
Link	A 1:1 relation between design entities represented as nodes. Links are typed and may be named.	Relation	8.12.1998
name (label)	Each label has a name which identifies the type of label. The name must be unique within the set of label types used in a design.	Attribute	8.12.1998
name (node)	Each node has a name which must be unique within a design. The name may be up to 64 characters long.	Attribute	15.11.1998

Object Models

- Object models describe the system in terms of object classes
- An object class is an abstraction over a set of objects with common attributes and the services (operations) provided by each object
- Various object models may be produced

Inheritance models

Aggregation models

Interaction models

- Natural ways of reflecting the real-world entities manipulated by the system
- More abstract entities are more difficult to model using this approach
- Object class identification is recognised as a difficult process requiring a deep understanding of the application domain
- Object classes reflecting domain entities are reusable across systems

Inheritance Models

- Organise the domain object classes into a hierarchy
- Classes at the top of the hierarchy reflect the common features of all classes
- Object classes inherit their attributes and services from one or more super-classes. These may then be specialised as necessary
- Class hierarchy design is a difficult process if duplication in different branches is to be avoided

The Unified Modelling Language

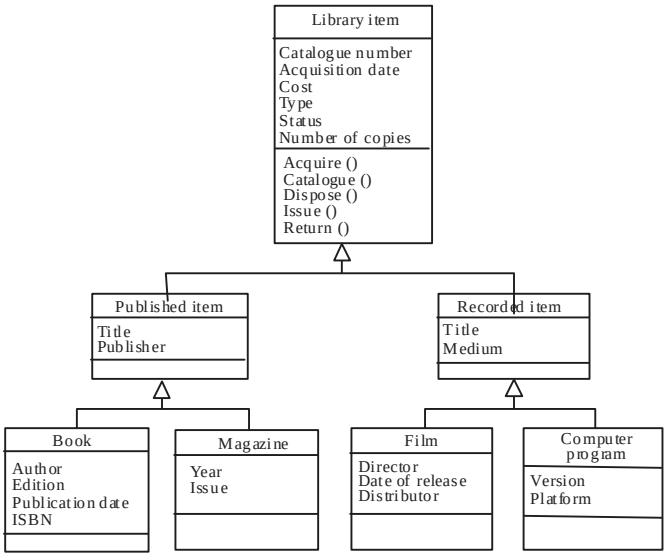
- Devised by the developers of widely used object-oriented analysis and design methods
- Has become an effective standard for object-oriented modelling
- Notation

Object classes are rectangles with the name at the top, attributes in the middle section and operations in the bottom section

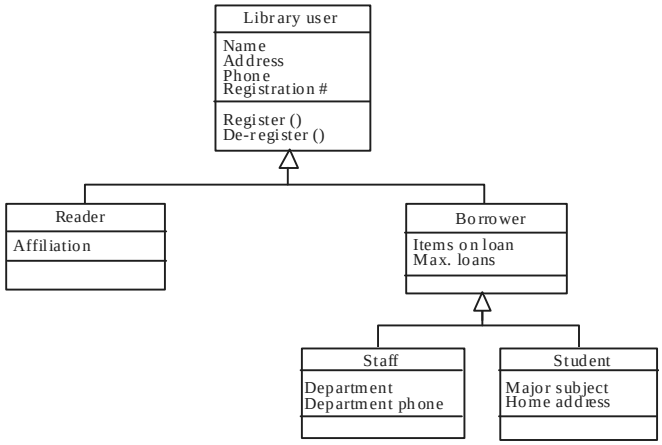
Relationships between object classes (known as associations) are shown as lines linking objects

Inheritance is referred to as generalisation and is shown 'upwards' rather than 'downwards' in a hierarchy

Library Class Hierarchy

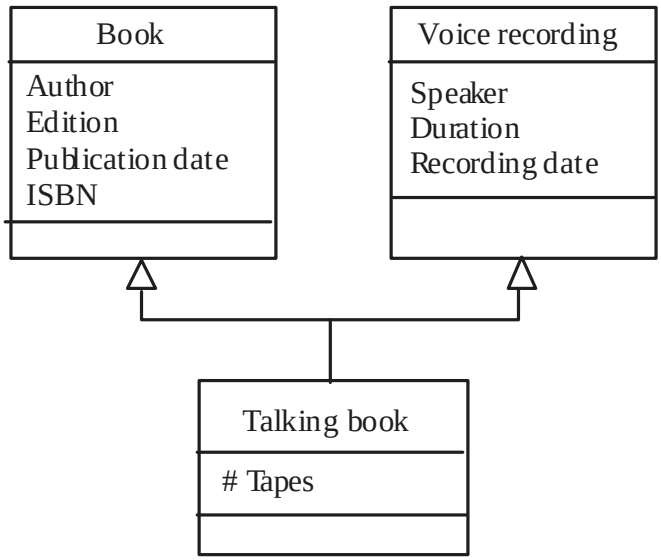


User Class Hierarchy



Multiple Inheritance

- Rather than inheriting the attributes and services from a single parent class, a system, which supports multiple inheritance, allows object classes to inherit from several super-classes
- Can lead to semantic conflicts where attributes/services with the same name in different super-classes have different semantics
- Makes class hierarchy reorganisation more complex



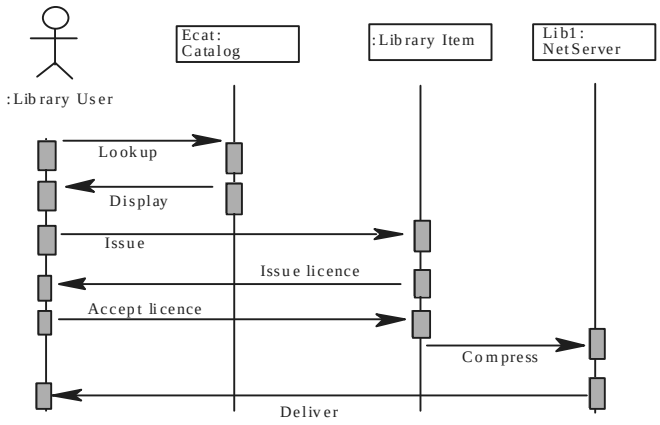
Object Aggregation

- Aggregation model shows how classes, which are collections, are composed of other classes
- Similar to the part-of relationship in semantic data models

Object Behaviour Modelling

- A behavioural model shows the interactions between objects to produce some particular system behaviour that is specified as a use-case
- Sequence diagrams (or collaboration diagrams) in the UML are used to model interaction between objects

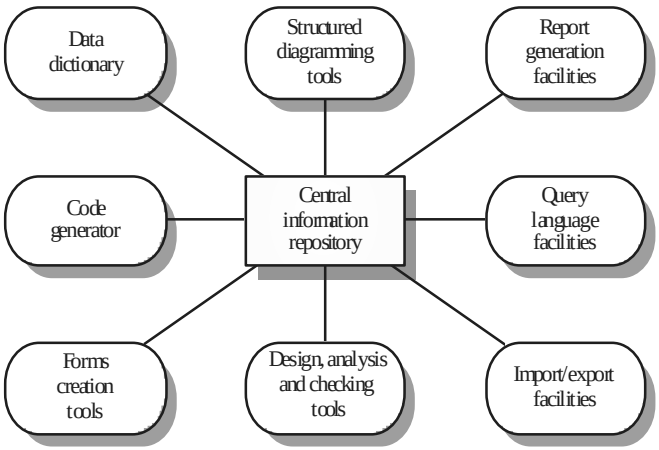
Issue of Electronic Items



CASE Workbenches

- A coherent set of tools that is designed to support related software process activities such as analysis, design or testing
- Analysis and design workbenches support system modelling during both requirements engineering and system design
- These workbenches may support a specific design method or may provide support for a creating several different types of system model

An Analysis and Design Workbench



Analysis Workbench Components

- Diagram editors
- Model analysis and checking tools
- Repository and associated query language
- Data dictionary
- Report definition and generation tools
- Forms definition tools
- Import/export translators
- Code generation tools

Key Points

- A model is an abstract system view. Complementary types of model provide different system information
- Context models show the position of a system in its environment with other systems and processes
- Data flow models may be used to model the data processing in a system
- State machine models model the system's behaviour in response to internal or external events
- Semantic data models describe the logical structure of data, which is imported to or exported by the systems
- Object models describe logical system entities, their classification and aggregation
- Object models describe the logical system entities and their classification and aggregation
- CASE workbenches support the development of system models

Activity

Draw a context model for a patient information system in a hospital. You may make any reasonable assumptions about the other hospital systems, which are available, but your model must include a patient admissions system and an image storage system for X-rays.

Activity

Based on your experience with a bank ATM, draw a data-flow diagram modeling the data processing involved when a customer withdraws cash form the machine.

Activity

Model the data processing which might take place in an electronic mail system. You should model the mail sending and mail receiving processing separately.

Activity

Draw state machine models of the control software for:

- An automatic washing machine, which has different programs for different types of clothes.
- The software for ac compact disc player.
- A telephone answering machine on an LED display. The system should allow the telephone owner to dial in, type a sequence of numbers (identified as tones) and have the recorded messages replayed over the phone.

Activity

Develop an object model including a class hierarchy diagram and an aggregation diagram showing the principal components of a personal computer system and its system software.

Activity

Develop a sequence diagram showing the interactions involved when a student registers for a course in a university. Courses may have a limited number of places so the registration process must include checks that places are available. Assume that the student accesses an electronic course catalogue to find out about available courses.

Activity

Describe three modeling activities that may be supported by a CASE workbench for some analysis method. Suggest three activities that cannot be automated.

Notes -

LESSSON 12 AND 13:
SOFTWARE PROTOTYPING

Objectives

- To describe the use of prototypes in different types of development projects
- To discuss evolutionary and throw-away prototyping

To introduce three rapid prototyping techniques:

High-level language development,

Database programming, and

Component reuse

- To explain the need for user interface prototyping

Topics Covered

- Prototyping in the software process
- Rapid prototyping techniques
- User interface prototyping

What is Prototyping?

- Some traditional features:

An iterative process emphasizing

Rapid development,

Evaluative use,

Feedback, and

Modification

Learning (based on feedback)

Consideration of alternatives

Concreteness (a "real system" is developed and presented to real users)

- Boundary between prototyping and normal system development blurs when an evolutionary (e.g., *agile*) development approach is used.

Uses of Prototypes

- Principal use is to help customers and developers better understand system requirements.

Experimentation stimulates anticipation of how a system could be used.

Attempting to use functions together to accomplish some task can easily reveal requirements problems.

- Other potential uses:

Evaluating proposed solutions for feasibility *(Experimental Prototyping)*

"Back-to-back" system testing

Training users before system delivery

- Prototyping is most often undertaken as a ***risk reduction*** activity.

Classifying Prototypes

- By purpose:

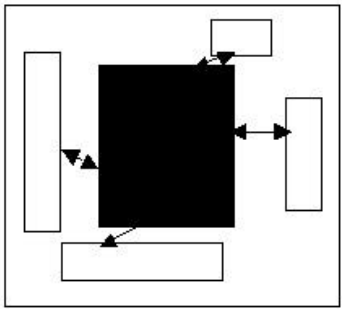
Throw-away prototyping : to elicit and validate requirements

Evolutionary prototyping : to deliver an acceptable, working system to end-users

Experimental prototyping : to evaluate proposed solutions for feasibility, performance, etc.

Simulation, Prototyping and Scenarios

- What are the differences between prototyping and simulation*?*



- What is the connection between simulation models / prototypes, scenarios*?*

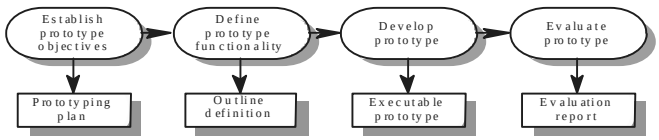
Simulation models are *automatic* scenario generators.

Prototypes facilitate *manual* scenario generation.

Prototyping Benefits

- Misunderstandings exposed.
- Difficult to use or confusing services identified
- Missing services detected
- Incomplete and/or inconsistent requirements found by analysts as prototype is being developed. Can demo feasibility and usefulness
- Basis for writing a system specification

Prototyping Process



Prototyping Outcomes

- Improved system usability
- Closer match to the system needed
- Improved design quality (maybe…)
- Improved maintainability (maybe…)
- Reduced overall development effort (maybe…but corrective maintenance costs are usually reduced)

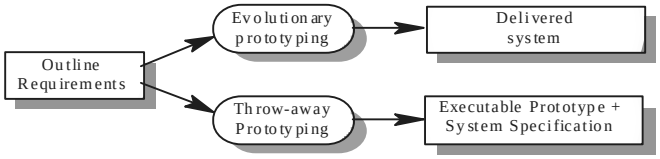
Prototyping in The Software Process

- Evolutionary prototyping : prototype is produced and refined through a number of stages to become the final system.
- Throwaway prototyping : prototype is produced to help elucidate / validate requirements and then discarded. The system is then developed using some other development process.

Starting Points

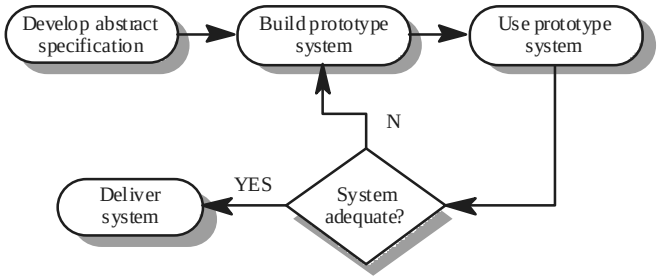
- In evolutionary prototyping, development starts with those requirements, which are best understood.
- In throwaway prototyping, development starts with those requirements, which are least understood.

Approaches to Prototyping



Evolutionary Prototyping

- Often used when a specification cannot be developed in advance (e.g., AI systems and GUI applications).
- System is developed as a series of prototype versions delivered to the customer for assessment.
- Verification is unnecessary as there is no specification.
- Validation involves assessing the adequacy of the system.



- Techniques for rapid system development are used such as CASE tools and 4GLs.
- User interfaces are usually developed using a GUI development toolkit.

Advantages of Evolutionary Prototyping Over Normal System Development

- Accelerated delivery : Quick availability is sometimes more important than details of functionality or maintainability.
- User engagement : System is more likely to meet user requirements and users are more likely to want to make it work.

Evolutionary Prototyping Problems

- Management problems

Poor fit with existing waterfall management model

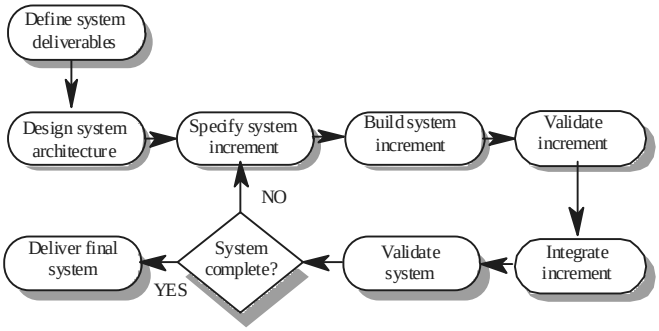
Specialized developer skills required

- Maintenance problems : Continual change tends to corrupt system structure so long-term maintenance is expensive.
- Contractual problems : No system requirements specification to serve as basis for contract

Incremental Development Revisited

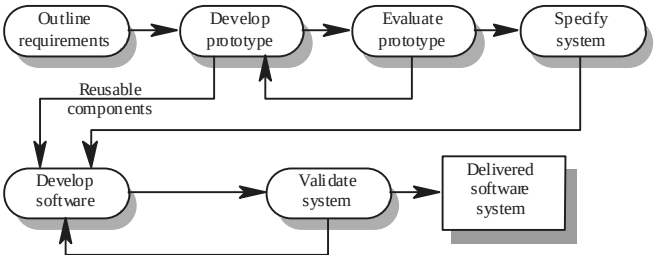
- System developed and delivered in increments after establishing an overall architecture.
- Users experiment with delivered increments while others are being developed.
- Intended to combine advantages of prototyping with a more manageable process and maintainable system structure.

Incremental Development Process



Throw-away Prototyping

- Used to reduce requirements risk.
- Initial prototype is developed from outline requirements, delivered for experiment, and modified until risk is acceptably low



Throw-away Prototype Delivery

- Developers may be ***pressurized*** to deliver a throw-away prototype as the final system.
- This is very problematic...

It may be impossible to meet non-functional requirements.

The prototype is almost certainly undocumented.

The system may be poorly structured and therefore difficult to maintain.

Normal quality standards may not have been applied.

Prototypes AS Specifications?

- Some parts of the requirements (e.g., safety-critical functions) may be impossible to prototype and so don't appear in the specification.

- An implementation has no legal standing as a contract.
- Non-functional requirements cannot be adequately represented in a system prototype.

Implementation Techniques

- Various techniques may be used for rapid development:

Dynamic high-level language development

Database programming (4GL's)

Component and application assembly

- These are not mutually exclusive : they are often used together.
- Visual programming is an inherent part of most prototype development systems.

Dynamic High-level Languages

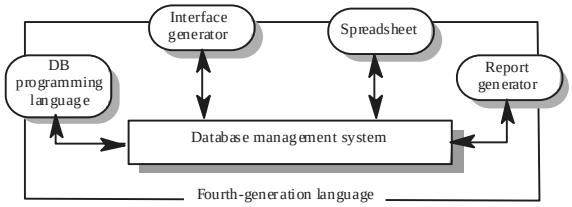
- Include powerful data management facilities : often type less and interpretive
- Require large run-time support system : not normally used for large system development.
- Some offer excellent GUI development facilities.
- Some have an integrated support environment whose facilities may be used in the prototype.
- Examples: Lisp (list structure based), Prolog (logic based), and Smalltalk (object-oriented)

Choice of Prototyping Language

- What is the application domain? (e.g., NLP?, matrix manipulation?)
- What user interaction is required? (text-based? Web-based?)
- What support environment comes with the language? (e.g., tools, components)
- What support environment comes with the language? (e.g., tools, components)
- Different parts of the system may be programmed in different languages. However, there may be problems with language communications.
- A multi-paradigm language (e.g., LOOPS) can reduce this problem.

Database Programming Languages

- Domain specific languages for business systems based around a database management system
- Normally include a database query language, a screen generator, a report generator and a spreadsheet.
- May be integrated with a CASE toolset
- The language + environment is some-times known as a fourth-generation language (4GL)
- Cost-effective for small to medium sized business systems
- Examples include Informix, Appgen, Sculptor, and Power-4GL.



Component and Application Assembly

- Prototypes can be created quickly from a set of reusable components plus some mechanism to "glue" these components together.
- The composition mechanism must include control facilities and a mechanism for component communication
- Must take into account the availability and functionality of existing components

Prototyping With Reuse

- Application level development

Entire application systems are integrated with the prototype so that their functionality can be shared.

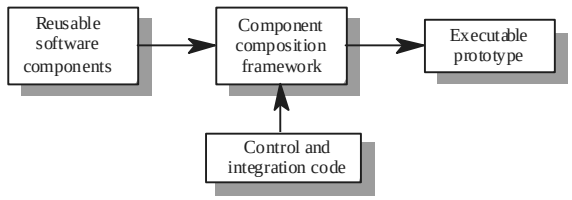
For example, if text preparation is required, a standard word processor can be used.

- Component level development

Individual components are integrated within a standard framework to implement the system

Framework can be a scripting language or an integration framework such as CORBA, DCOM, or Java Beans

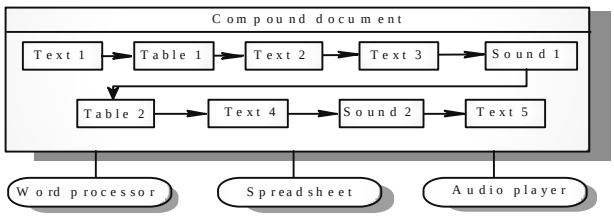
Reusable Component Composition



Compound Documents

- For some applications, a prototype can be created by developing a compound document.
- This is a document with active elements (such as a spreadsheet) that allow user computations.
- Each active element has an associated application, which is invoked when that element is selected.
- The document itself is the integrator for the different applications.

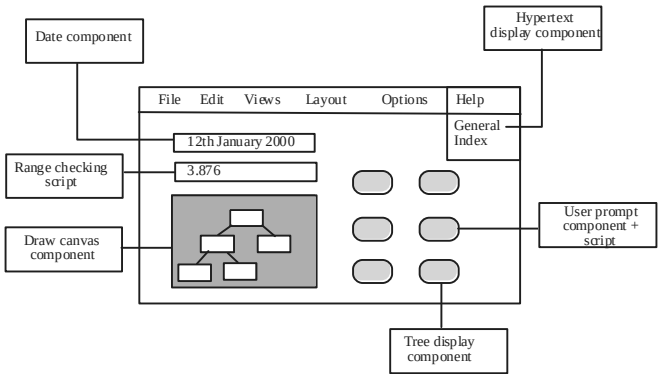
Application Linking in Compound Documents



Visual Programming

- Scripting languages such as Visual Basic support visual programming where the prototype is developed by creating a user interface from standard items and associating components with these items.
- A large library of components exists to support this type of development
- These may be tailored to suit the specific application requirements.

Visual Programming With Reuse



Problems With Visual Development

- Difficult to coordinate team-based development
- No explicit system architecture (hidden)
- Complex dependencies between parts of the program can cause maintainability problems.

User Interface Prototyping

- It is impossible to pre-specify the look and feel of a user interface in an effective way. Prototyping is essential.
- UI development consumes an increasing part of overall system development costs
- User interface generators may be used to “draw” the interface and simulate its functionality with components associated with interface entities.
- Web interfaces may be prototyped using a web site editor.

Key Points

- A prototype can be used to give end-users a concrete impression of the system’s capabilities.
- Prototyping is becoming increasingly used for system development where rapid development is essential.
- Throw-away prototyping is used to understand the system requirements.
- In evolutionary prototyping, the system is developed by evolving an initial version to the final version.
- Rapid development of prototypes is essential. This may require leaving out functionality or relaxing non-functional constraints.
- Prototyping techniques include the use of very high-level languages, database programming and prototype construction from reusable components.
- Prototyping is essential for parts of the system such as the user interface, which cannot be effectively pre-specified. Users must be involved in prototype evaluation

Activity

You have been asked to investigate the feasibility of prototyping in the software development process in your organization. Write a report for your manager discussing the classes of project where prototyping should be used and setting out the expected costs and benefits form using prototyping.

Activity

Explain why, for large systems development, it is recommended that prototypes should be throw away prototypes.

Activity

Under what circumstances would you recommend that prototyping should be used as a means of validating system requirements?

Activity

Discuss prototyping using reusable components and suggest problems which may arise using this approach. What is the most effective way to specify reusable components?

Activity

Suggest difficulties that might arise when prototyping real time embedded computer systems :

Activity

You have been asked by a charity to prototype a system that keeps track of tall donations they have received. This system has to maintain the names and addresses of donors, their particular interests, the amount donated, and when it was donation (e.g. it must be spent on a particular project) and the system must keep track of these donations and how they were spent. Discuss how you would prototype this system bearing in mind that the charity has a mixture of paid workers and volunteers. Many of the volunteers are retirees who have had little or no computer experience.

Activity

You have developed a throw prototype system for a client who is very happy with it. However, she suggests that there is no need to develop another system but that you should deliver the prototype and offers an excellent price for the system. You know that there may be future problems with maintaining the system. Discuss how you might respond to this customer.

Notes:

LECTURE 14:
FORMAL SPECIFICATIONS

Objectives

- To explain why formal specification helps discover problems in system requirements.
- To describe the use of:

Algebraic specification techniques, and

Model-based specification techniques (including simple pre and post conditions).

Topics Covered

- Formal specification in the software process
- Interface specification
- Behavioural specification

Formal Methods

- Formal specification is part of a more general collection of techniques known as "formal methods."
- All are based on the mathematical representations and analysis of requirements and software.
- Formal methods include:

Formal specification

Specification analysis and property proofs

Transformational development

Program verification (program correctness proofs)

- Specifications are expressed with precisely defined vocabulary, syntax, and semantics.

Acceptance and Use

- Formal methods have not become mainstream as was once predicted, especially in the US.

Other, less costly software engineering techniques (e.g., inspections / reviews) have been successful at increasing system quality. (Hence, the need for formal methods has been reduced.)

Market changes have made time-to-market rather than quality the key issue for many systems. (Formal methods do not reduce time-to-market.)

The scope of formal methods is limited. They are not well suited to specifying user interfaces. (Many interactive applications are "GUI-heavy" today.)

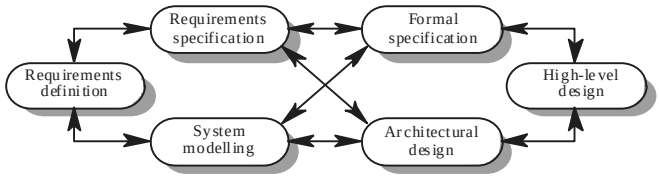
Formal methods are hard to scale up to very large systems. (Although this is rarely necessary.)

The costs of introducing formal methods are high.

Thus, the risks of adopting formal methods on most projects outweigh the benefits.

- However, formal specification is an excellent way to find requirements errors and to express requirements unambiguously.
- Projects, which use formal methods invariably, report fewer errors in the delivered software.
- In systems where failure must be avoided, the use of formal methods is justified and likely to be cost-effective.
- Thus, the use of formal methods is increasing in critical system development where safety, reliability, and security are important.

Formal Specification in The Software Process



Formal Specification Techniques

	Sequential	Concurrent
Algebraic	Larch (Guttag, Horning et al., 1985; Guttag, Horning et al., 1993), OBJ (Futatsugi, Goguen et al., 1985)	Lotos (Bolognesi and Brinksma, 1987),
Model-based	Z (Spivey, 1992) VDM (Jones, 1980) B (Wordsworth, 1996)	CSP (Hoare, 1985) Petri Nets (Peterson, 1981)

Algebraic approach : the system is specified in terms of its operations and their relationships via axioms.

Model-based approach (including simple pre- and post-conditions) : the system is specified in terms of a state model and operations are defined in terms of changes to system state.

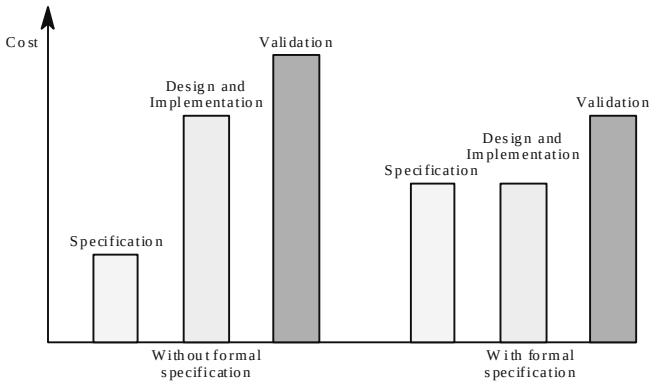
Formal Specification Languages

	Sequential	Concurrent
Algebraic	Larch (Guttag, Horning et al., 1985; Guttag, Horning et al., 1993), OBJ (Futatsugi, Goguen et al., 1985)	Lotos (Bolognesi and Brinksma, 1987),
Model-based	Z (Spivey, 1992) VDM (Jones, 1980) B (Wordsworth, 1996)	CSP (Hoare, 1985) Petri Nets (Peterson, 1981)

Use of Formal Specification

- Formal specification is a rigorous process and requires more effort in the early phases of software development.
- This reduces requirements errors as ambiguities, incompleteness, and inconsistencies are discovered and resolved.
- Hence, rework due to requirements problems is greatly reduced.

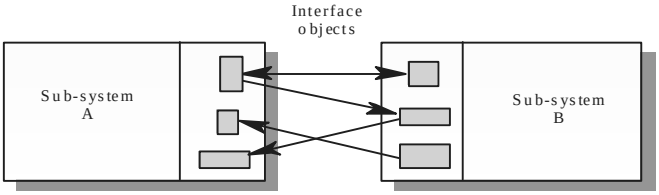
Development Costs With Formal Specification



Specification of Sub-system Interfaces

- Large systems are normally comprised of sub-systems with well-defined interfaces.
- Specification of these interfaces allows for their independent development.
- Interfaces are often defined as abstract data types or objects.
- The algebraic approach is particularly well suited to the specification of such interfaces.

Sub-system Interfaces



Specification Components

- Introduction : defines the sort (type name) and declares other specifications that are used
- Description : informally describes the operations on the type
- Signature : defines the syntax of the operations in the interface and their parameters
- Axioms : defines the operation semantics by defining axioms which characterize behaviour

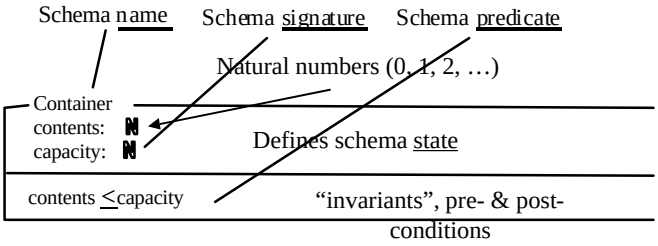
Types of Operations

- Constructor operations: operations which create / modify entities of the type
- Inspection operations: operations, which evaluate entities of the type being specified
- Rule of thumb for defining axioms: define an axiom, which sets out what is always true for each inspection operation over each constructor

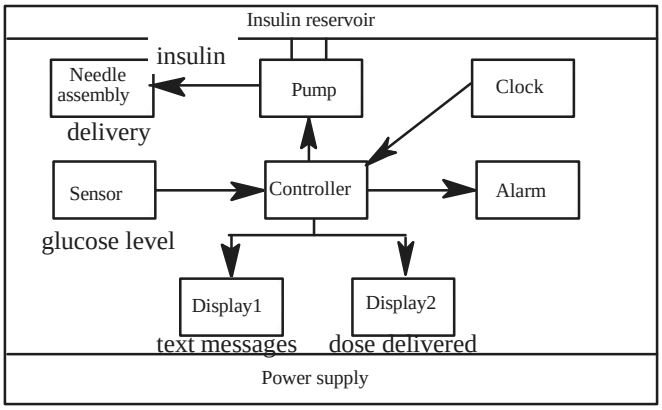
Model-based Specification

- Algebraic specification can be cumber-some when object operations are not independent of object state (i.e., previous operations).
- (System State) Model-based specification exposes the system state and defines operations in terms of changes to that state.
- Z is a mature notation for model-based specification. It combines formal and informal descriptions and incorporates graphical highlighting.
- The basic building blocks of Z-based specifications are schemas.
- Schemas identify state variables and define constraints and operations in terms of those variables.

The Structure of A Z Schema



An Insulin Pump



Modelling The Insulin Pump

- The schema models the insulin pump as a number of state variables

reading?	-from sensor dose, cumulative dose
r0, r1, r2	-last 3 readings
capacity	-pump reservoir
alarm!	-signals exceptional conditions
pump!	-output for pump device
display1!, display2!	-text messages & dose

- Names followed by a? are inputs, names followed by a! are outputs.

Schema Invariant

- Each Z schema has an invariant part, which defines conditions that are always true (schema predicates)
- For the insulin pump schema, it is always true that:

The dose must be less than or equal to the capacity of the insulin reservoir.

No single dose may be more than 5 units of insulin and the total dose delivered in a time period must not exceed 50 units of insulin. This is a safety constraint.

display1! shows the status of the insulin reservoir.

Insulin Pump Schema

```
Insulin_pump
reading? : ℕ
dose, cumulative_dose: ℕ
r0, r1, r2: ℕ      // used to record the last 3 readings taken
capacity: ℕ
alarm!: {off, on}
pump!: ℕ
display1!, display2!: STRING
---
dose ? capacity ∧  dose ? 5 ∧ cumulative_dose ? 50
capacity ? 40 => display1! = " "
capacity ? 39 ∧ capacity ? 10 => display1! = "Insulin low"
capacity ? 9 => alarm! = on ∧ display1! = "Insulin very low"
r2 = reading?
```

every 10 minutes…

The Dosage Computation

- The insulin pump computes the amount of insulin required by comparing the current reading with two previous readings.
- If these suggest that blood glucose is rising then insulin is delivered.
- Information about the total dose delivered is maintained to allow the safety check invariant to be applied.
- Note that this invariant always applies – there is no need to repeat it in the dosage computation.

DOSAGE Schema

operations change state

```
DOSAGE
ΔInsulin_Pump
---
(
dose = 0 ∧
  (
        ((r1 ? r0) ∧ (r2 = r1)) V
        ((r1 > r0) ∧ (r2 < r1)) V
        ((r1 < r0) ∧ ((r1-r2) > (r0-r1)))
  ) ∨
 dose = 4 ∧
  (
        ((r1 ? r0) ∧ (r2 = r1)) V
        ((r1 < r0) ∧ ((r1 – r2) ? (r0 – r1)))
  ) ∨
dose =(r2 -r1) * 4 ∧
  (
        ((r1 ? r0) ∧ (r2 > r1)) V
        ((r1 > r0) ∧ ((r2 – r1) ? (r1 – r0)))
  )
)
capacity' = capacity - dose
cumulative_dose' = cumulative_dose + dose
r0' = r1 ∧ r1' = r2
```

imports state & predicates

x?- value of x after operation

Output Schemas

- The output schemas model the system displays and the alarm that indicates some potentially dangerous condition.
- The output displays show the dose computed and a warning message.
- The alarm is activated if blood sugar is very low – this indicates that the user should eat something to increase his blood sugar level.

```
DISPLAY
ΔInsulin_Pump
---
display2!' = Nat_to_string (dose) ∧
(reading? < 3 ⇒ display1!' = "Sugar low" ∨
reading? > 30 ⇒ display1!' = "Sugar high" ∨
reading? ? 3  and reading? ? 30  ⇒ display1!' = "OK")
```

conversion

Note conflict with "insulin low" msg.

```
ALARM
ΔInsulin_Pump
---
(reading? < 3 ∨ reading? > 30 ) ⇒ alarm!' = on ∧
(reading? ? 3 ∧ reading? ? 30 ) ⇒ alarm!' = off
```

AND

Schema Consistency

- It is important that schemas be consistent. Inconsistency suggests a problem with system requirements.
- The INSULIN_PUMP schema and the DISPLAY are inconsistent:

display1! shows a warning message about the insulin reservoir (INSULIN_PUMP)

display1! Shows the state of the blood sugar (DISPLAY)

- This must be resolved before implementation of the system.

Secification Via Pre-and Post-conditions

- Predicates that (when considered together) reflect a program's intended functional behavior are defined over its state variables.
- Pre-condition: expresses constraints on program variables before program execution. An implementer may assume these will hold BEFORE program execution.
- Post-condition: expresses conditions / relationships among program variables after execution. These capture any obligatory conditions AFTER program execution.
- Language: (first order) predicate calculus

Predicates (X>4)

Connectives (&, V, $\rightarrow$, ó, NOT)

Universal and existential quantifiers (for every, there exists…)

Rules of inference (if A & (A $\rightarrow$B) then B)

Example 1

Sort a non-empty array LIST [1..N] into increasing order.

Pre-cond: N $\geq$1

Post-cond: For_Every i, 1 $\leq$ i $\leq$ N-1, LIST [i] $\leq$ LIST [i+1] & PERM (LIST, LIST')

Example 2

Search a non-empty, ordered array LIST [1..N] for the value stored in KEY. If present, set found to true and J to an index of LIST which corresponds to KEY. Otherwise, set FOUND to false.

Pre-cond: $N \geq 1$ & [("LIST is in increasing order") V ("LIST is in decreasing order")]
(Exercise: express the "ordered" predicate above FORMALLY.)
Post-cond: [(FOUND & There Exists i, $1 \leq i \leq N$ | J=i & LIST [J]=Key) V (NOT FOUND & For_Every i, $1 \leq i \leq N$, LIST [i] $\neq$ KEY)] & UNCH (LIST, KEY)

Key Points

- Formal system specification complements informal specification techniques.
- Formal specifications are precise and unambiguous. They remove areas of doubt in a specification.
- Formal specification forces an analysis of the system requirements at an early stage. Correcting errors at this stage is cheaper than modifying a delivered system.
- Formal specification techniques are most applicable in the development of critical systems.
- Algebraic techniques are particularly suited to specifying interfaces of objects and abstract data types.
- In model-based specification, operations are defined in terms of changes to system state.

Activity

Suggest why the architectural design of a system should precede the development of a formal specification.

Activity

You have been given the task of selling formal specification techniques to a software development organization. Outline how you would go about explaining the advantages of formal specifications to skeptical, practicing software engineers.

Activity

Explain why it is particularly important to define sub-system interfaces in a precise way and why algebraic specification is particularly appropriate for sub-system interface specification.

Activity

In the example of a controlled airspace sector, the safety condition is that aircraft may not be within 300 m of height in the same sector. Modify the specification shown in figure 9.8 to allow aircraft to occupy the same height in the sector so long as they are separated by at least 8km of horizontal difference. You may ignore aircraft in adjacent sectors. Hint. You have to modify the constructor operations so that they include the aircraft position as well as its height. You also have to define an operation that, given two positions, returns the separation between them.

Activity

Bank teller machines rely on using information on the user's card giving the bank identifier, the account number and the user's personal identifier. They also derive account information from a central database and update that database on completion of a transaction. Using your knowledge of ATM operation write Z schemas defining the state of the system, card validation (where the user's identifier is checked) and cash withdrawal.

Activity

You are a systems engineer and you are asked to suggest the best way to develop the safety software for a heart pacemaker. You suggest formally specifying the system but your suggestion is rejected by your manager. You think his reasons are weak and based on prejudice. Is it ethical to develop the system using methods that you think are inadequate?

LESSON15 AND 16:
ARCHITECTURAL DESIGN

Establishing The Overall Structure of a Software System

Objectives

- To introduce architectural design and to discuss its importance
- To explain why multiple models are required to document in architecture
- To describe types of architectural models that may be used
- To discuss use of domain-specific architectural reference models

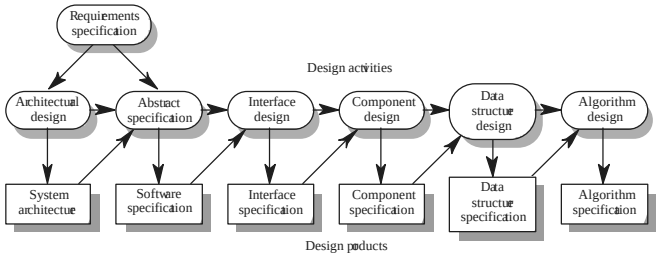
Topics Covered

- Architectural design
- System structuring
- Control models
- Modular decomposition
- Domain-specific architectures

What is Architectural Design?

- The process of identifying the sub-systems making up a system and a framework for sub-system control and communication.
- A boot-strapping process undertaken in parallel with the abstract specification of sub-systems.
- The output of this process is the software architecture.

The Software Design Process



Advantages of explicit architecture design and documentation (Bass)

- Stakeholder communication : the architecture may be used as a focus of discussion by system stakeholders.
- System analysis : the feasibility of meeting critical non-functional requirements (e.g., performance, reliability, maintainability) can be studied early on.
- Large-scale reuse : the architecture may be reusable across a range of systems with similar requirements.

Architectural Design Process

- System structuring : the system is decomposed into major sub-systems and communication (e.g., data sharing) mechanisms are identified.
- Control modelling : a model of the control relationships between the sub-systems is established.
- Modular decomposition : the identified sub-systems are decomposed into lower-level *modules* (components, objects, etc.)

Terminology Issues

- Modular decomposition is sometimes called high-level (system) design.
- A sub-system is usually a system in its own right, and is sometimes called a Product.
- A module is a lower-level element that would not normally be considered a separate system; modules are sometimes called Components or Objects.
- Traditional (and Somerville's) terminology

  System (System)

  Product (Sub-System)

  Component (Module)

  Module (Unit) (Algorithm)

Architectural Models

- Different types of models may be used to represent an architectural design.
- Each presents a different perspective on the architecture.

Architectural Model Types

- Static structural models show the major system components.
- Dynamic process models show the process structure of the system at run-time.
- Interface models define the sub-system services offered through public interfaces.
- Relationship models show relationships such as a dataflow among sub-systems.

Architectural Styles

- The architecture of a system may conform to a single generic model or style, although most do not.
- An awareness of these styles and how they can affect system attributes can simplify the problem of choosing an appropriate architecture.

System Attributes And Architectural Styles / Structures

- Performance : localize operations by using fewer, large-grain components to minimize sub-system communication.
- Security : use a layered architecture with critical assets in inner layers.
- Safety : isolate safety-critical components in one or just a few sub-systems.

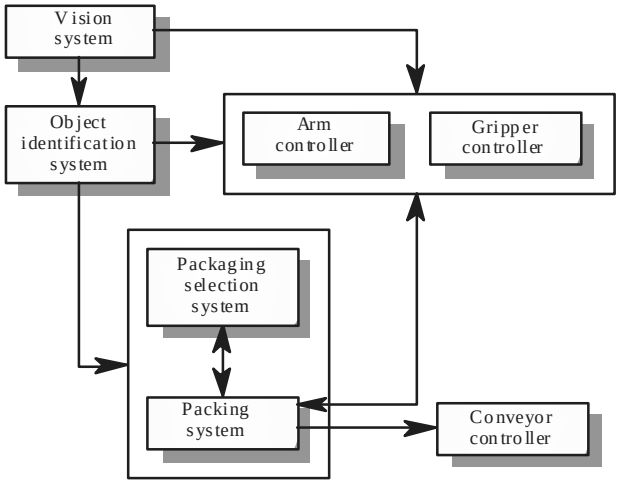
Availability : include redundant components in the architecture.

- Maintainability : use fine-grain, self-contained components.

System Structuring

- Concerned with decomposing the system into interacting sub-systems.
- The architectural design is normally expressed as a block diagram presenting an overview of the system structure.
- More specific models showing how sub-systems share data are distributed, and interface with each other may also be developed. (Examples follow.)

Packing Robot Control System



The Repository Model

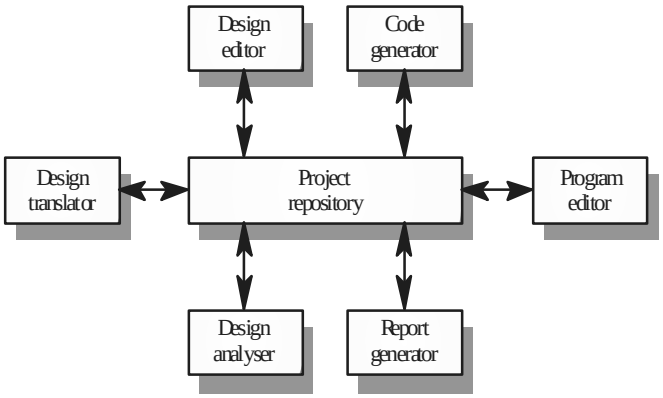
- Sub-systems must exchange info. This may be done in two ways:

Shared data is held in a central database or repository and may be accessed by all sub-systems.

Each sub-system maintains its own database and passes data explicitly to other sub-systems.

- When large amounts of data are used, the repository model of sharing is commonly used.

CASE Toolset Architecture



Repository Model Advantages

- Simple and efficient way to share large amounts of data locally.
- Sub-systems, which use data, need not be concerned with how that data is produced, and vice-versa.
- Management activities such as backup, access control, and recovery are centralized.
- Sharing model is published as the repository schema. Integration of compatible tools is relatively easy.

Repository Model Disadvantages

- Sub-systems must agree on a single repository data model. This is inevitably a compromise.
- Data model evolution is difficult and expensive.
- No provision for sub-system-specific data management requirements related to backup, access control, and recovery.
- May be difficult to distribute efficiently over a number of machines due to problems with data redundancy and inconsistency.

The Client-server Model

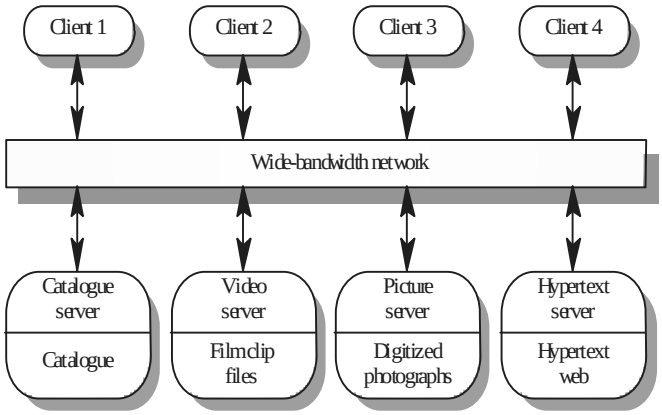
- Distributed system model, which shows how data and processing are distributed across a range of processors.
- Major components are:

A set of stand-alone servers, which provide specific services such as printing, file management, etc.

A set of clients, which call on these services

A network, which allows clients to access these services

Film and Picture Library



Client-server Model Advantages

- Supports distributed computing.
- Underlying network makes distribution of data straightforward.
- No shared data model so servers may organize data to optimise their performance.
- Distinction between servers and clients may allow use of cheaper hardware.
- Relatively easy to expand or upgrade system.

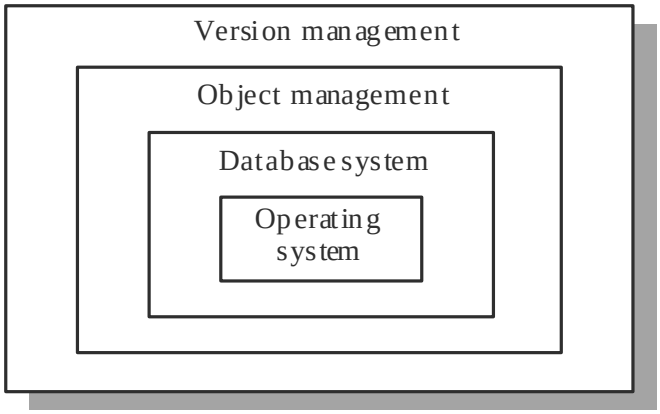
Client-server Model Disadvantages

- Relatively complex architecture – problem determination can be difficult.
- No shared data model so data integration may be problematic.
- Redundant data management in each server.
- No central register of names and services, so it may be hard to find out what servers and services are available.

The Abstract Machine Model

- Organizes a system into a series of layers.
- Each layer defines an abstract machine and provides a set of services used to implement the next level of abstract machine.
- When a layer interface changes, only the adjacent layer is affected.
- However, it is often difficult to structure systems in this way. (Why?)

Abstract Machine Based Version Management System



Control Models

- Concerned with the control flow between sub-systems. Distinct from the system structure model.
- Two general approaches:

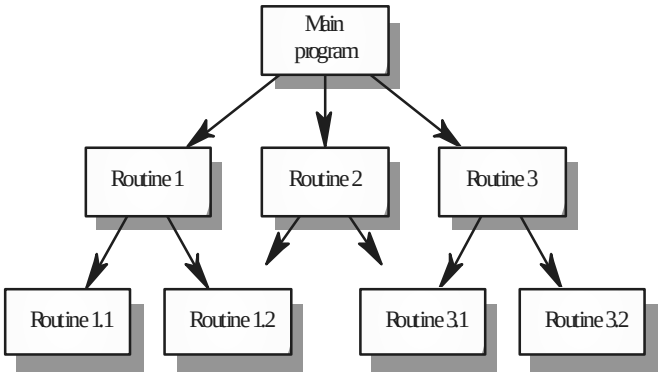
Centralized control : one sub-system has overall responsibility for control and starts and stops other sub-systems.

Event-based control : each sub-system can respond to externally generated events from other sub-systems, or from the system's environment.

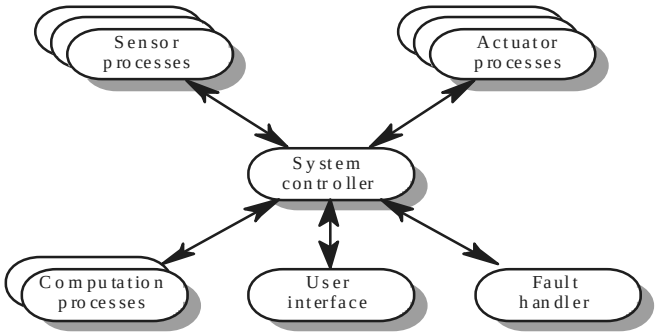
Centralized Control Models

1. Call-return model : top-down subroutine model where control starts at the top of a subroutine hierarchy and moves downwards. Applicable to sequential systems only.
2. Manager model : applicable to concurrent systems. One system component controls the stopping, starting and coordination of other system processes. Also applicable to sequential systems where it is usually implemented as a case statement within a management routine.

Call-return Model



Manager Model - Real-time System Control



Principal Event-based Control Models

1. Broadcast model : an event is broadcast to all sub-systems; any sub-system, which can handle the event, may do so.
2. Interrupt-driven model : used in real-time systems where interrupts are detected by an interrupt handler and passed to some other component for processing.

(Other event-based models include compound documents and production systems.)

Broadcast Model

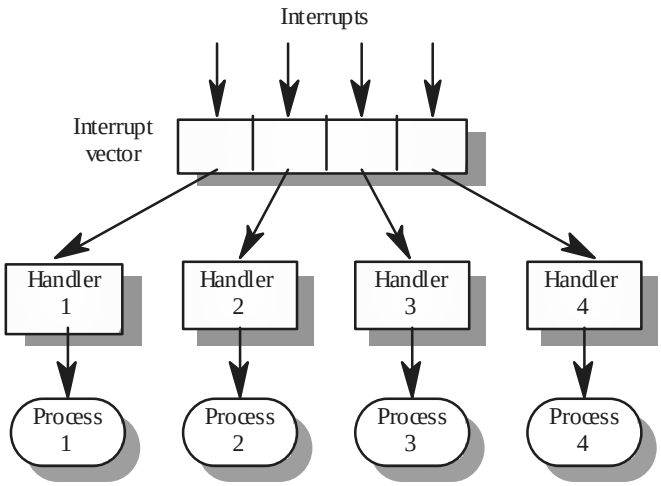
- Effective in integrating sub-systems executing on different computers in a network.
- Control policy is NOT embedded in the message handler; sub-systems register an interest in specific events and the event handler ensures that these events are sent to them.
- Registration of interests' supports selective broadcasting.
- Evolution is relatively easy since a new sub-system can be integrated by registering its events with the event handler.
- However, sub-systems don't know if or when an event will be handled by some other sub-system.

Interrupt-driven Systems

- Used in real-time systems where fast response to an event is essential.
- A handler is defined for each type of interrupt.
- Each type is associated with a memory location and a hardware switch causes transfer to its handler – fast!

- Allows fast response but is complex to program and difficult to verify. (Why?)

Interrupt-driven Control



Modular Decomposition (A.K.A. High-level Design)

- Sub-systems are decomposed into lower-level elements.
- Two models are considered:

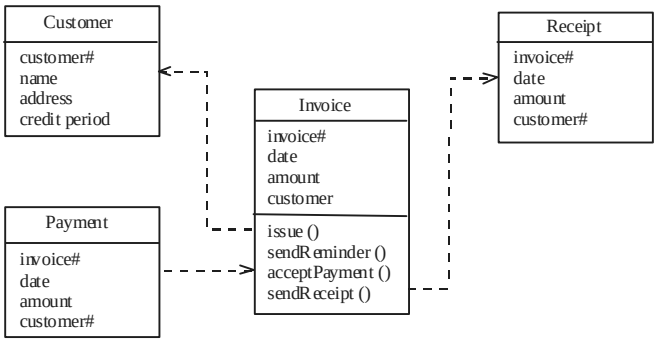
An object model where the system is decom-posed into interacting objects. (object-oriented design)

A data-flow model where the system is decomposed into functional modules, which transform inputs into outputs. (function-oriented design)

Object Models

- Structure the system into a set of loosely coupled objects with well-defined interfaces.
- Object-oriented decomposition is concerned with identifying object classes, their attributes and operations.
- When implemented, objects are created from these classes and some control model is used to coordinate object operations.

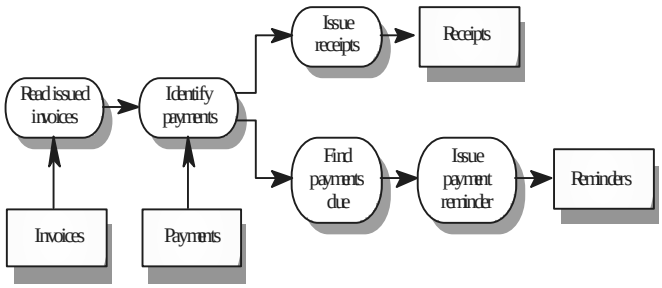
Invoice Processing System



Data-flow Models

- Functional transformations process inputs to produce outputs.
- Sometimes referred to as a pipe and filter model (after terminology used in UNIX).
- Variants of this approach have a long history in software design.
- When transformations are sequential, this is a batch sequential model
- Which is extensively used in data processing systems.
- Not really suitable for interactive systems (input data streams versus events)

Invoice Processing System



Domain-specific Architectures

- Architectural models which are specific to some application domain
- Two types of domain-specific models:

1.Generic models encapsulate the traditional, time-tested characteristics of real systems.

2.Reference models are more abstract and describe a larger class of systems. They provide a means of comparing different systems in a domain.

- Generic models are usually bottom-up models; Reference models are top-down models.

Generic Models

- The compiler model is a well-known example.
- Based on the thousands written, it is now generally agreed that the standard components of a compiler are:

Lexical analyser

Symbol table

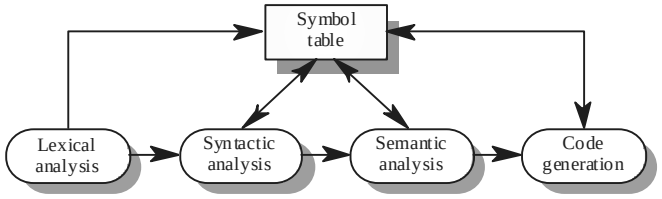
Syntax analyser

Syntax tree

Semantic analyser

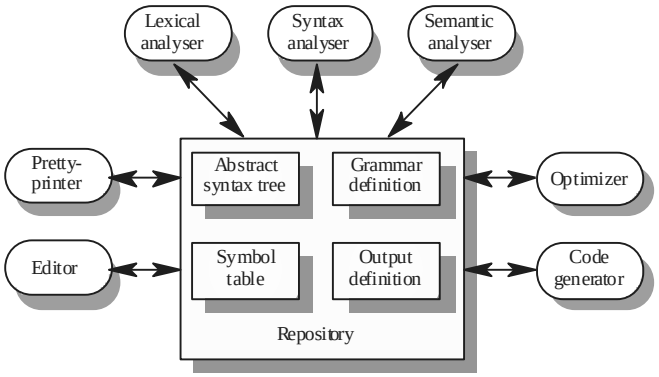
Code generator

Compiler Model



Sequential function model (batch processing oriented)

Language Processing System

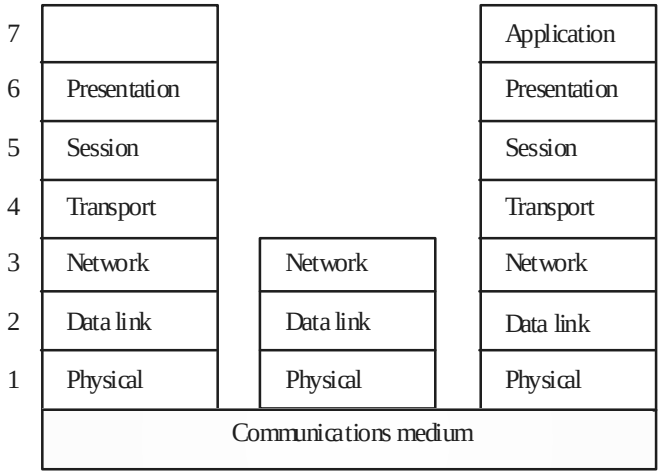


Repository-based model

Reference Architectures

- Reference models are derived from a study of the application domain rather than from existing systems.
- May be used as a basis for system implementation, or to compare different systems. It acts as a standard against which systems can be evaluated.
- The OSI (Open System Interconnection) model is a layered model for communication systems (in particular, data processing / point-of-sale applications).

OSI Reference Model



Key Points

- The software architect is responsible for deriving a structural system model, a control model, and a sub-system decomposition model.
- Large systems rarely conform to a single architectural model.
- System decomposition models include the repository model, client-server model, and abstract machine model.
- Control models include centralized control and event-driven models.
- Modular decomposition models include data-flow and object models.
- Domain specific architectural models are abstractions over an application domain.
- They may be constructed by abstracting from existing systems or they may be idealized reference models.

Activity

Explain why it may be necessary to design the system architecture before the specifications are written.

Activity

Construct a table showing the advantages and disadvantages of the different structural models discussed in this chapter.

Activity

Giving reasons for your answer, suggest an appropriate structural model for the following systems:

- An automated ticket issuing system used by passengers at a railway station.
- A computer controlled video conferencing system, which allows video, audio, and computer data to be visible to several participants at the same time.
- A robot floor cleaner, which is intended to clean relatively, clear spaces such as corridors. The cleaner must be able to sense walls and other obstructions.

Activity

Design an architecture for the above systems based on your choice of model. Make reasonable assumptions about the system requirements.

Activity

Explain why a call-return model of control is not usually suitable for real time systems which control some process.

Activity

Giving reasons for your answer, suggest an appropriate control model for the following systems:

- A batch processing system, which takes information about hours, worked and pays rates and prints salary slips and bank credit transfer information.
- A set of software tools, which are, produced buy different vendors but which mist work together.
- A television controller, which responds to, signals form a remote control unit.

Notes:

Activity

Discuss their advantages and disadvantages as far as disreputability is concerned of the data flow model and the object model. Assume that both single machine and distributed versions of an application are required.

Activity

Should there be a separate profession of 'software architect' whose role is to work independently with a customer to design a software architecture? This would then be implemented by some software company. What might be the difficulties of establishing such a profession?

LESSON17 AND 18: DISTRIBUTED SYSTEMS ARCHITECTURES

Architectural Design for Software That Executes on More Than One Processor

Objectives

- To explain the advantages and disadvantages of distributed systems architectures.
- To describe different approaches to the development of client-server systems.
- To explain the differences between client-server and distributed object architectures.
- To describe object request brokers and the principles underlying the CORBA standards.

Topics Covered

- Multiprocessing systems
- Distributed systems architectures

Client-server architectures

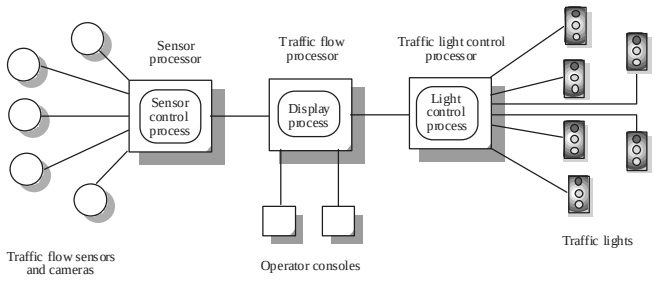
Distributed object architectures

- CORBA (Common Object Request Broker Architecture)

Multiprocessor Architectures

- System composed of multiple processes, which may or may not execute on different processors.
- Distribution of process to processor may be pre-ordered or may be under the control of a dispatcher.

A Multiprocessor Traffic Control System



Types of Multiprocessing Systems

- Personal systems that are not distributed and that are designed to run on a personal computer or workstation. (word processors)
- Embedded systems that run on a single processor or on an integrated group of processors. (control systems, real-time systems)
- Distributed systems where the system software runs on a loosely integrated group of processors linked by a network. (ATM systems)

Distributed Systems

- Virtually all-large, computer-based systems are now distributed systems.
- Processing is distributed over several computers rather than confined to a single machine.
- Distributed software engineering is now very important.

Distributed System Characteristics / Advantages

- Resource sharing (hardware and software)
- Openness (resource extendibility)
- Concurrency (parallel processing)
- Scalability (up to capacity of network)
- Fault tolerance (potential)
- Transparency (ability to conceal distributed nature)

Distributed System Disadvantages

- Complexity (no. of factors affecting emergent properties)
- Security (multiple access points, network eavesdropping)
- Manageability (heterogeneity)
- Unpredictable responsiveness

Issues in Distributed System Design

Design issue	Description
Resource identification	The resources in a distributed system are spread across different computers and a naming scheme has to be devised so that users can discover and refer to the resources that they need. An example of such a naming scheme is the URL (Uniform Resource Locator) that is used to identify WWW pages. If a meaningful and universally understood identification scheme is not used then many of these resources will be inaccessible to system users.
Communications	The universal availability of the Internet and the efficient implementation of Internet TCP/IP communication protocols means that, for most distributed systems, these are the most effective way for the computers to communicate. However, where there are specific requirements for performance, reliability etc. alternative approaches to communications may be used.
Quality of service	The quality of service offered by a system reflects its performance, availability and reliability. It is affected by a number of factors such as the allocation of processes to processes in the system, the distribution of resources across the system, the network and the system hardware and the adaptability of the system.
Software architectures	The software architecture describes how the application functionality is distributed over a number of logical components and how these components are distributed across processors. Choosing the right architecture for an application is essential to achieve the desired quality of service.

Distributed Systems Architectures

- Client-server architectures : Ristributed services, which are called on by clients. Servers that provide services are treated differently from clients that use services.
- Distributed object architectures : Removes distinction between clients and servers. Any object in the system may provide and use services from other objects.

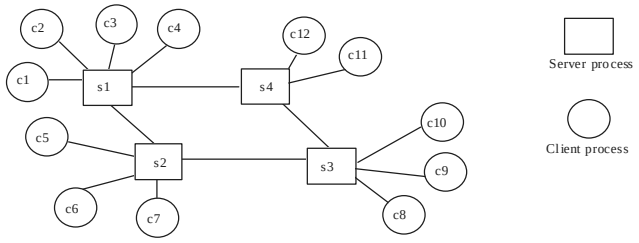
Middleware

- Software that manages and enables communication between the diverse components of a distributed system. Middleware is usually off-the-shelf rather than specially written.
- Distributed system frameworks, e.g. CORBA and DCOM, is an important class of middle-ware described later.

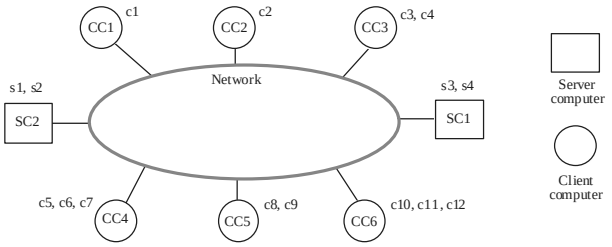
Client-server Architectures

- The application is modelled as a set of services that are provided by servers and a set of clients that use the services.
- Clients must know of servers but servers need not know of clients. (e.g., “installing” a network printer)
- Clients and servers are logical processes as opposed to physical machines.
- The mapping of processors to processes is not necessarily 1:1.

A Client-server System



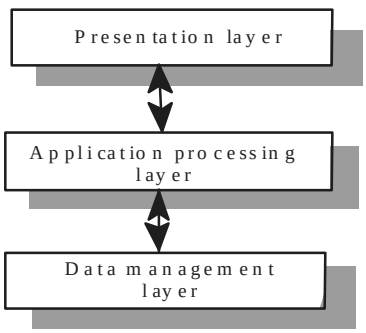
Computers in a C/S Network



Application Layers Model

- Presentation layer : concerned with presenting the results of a computation to system users and with collecting user inputs.
- Application processing layer : concerned with implementing the logic (functionality) of the application.
- Data management layer : concerned with all system database operations.

Application Layers



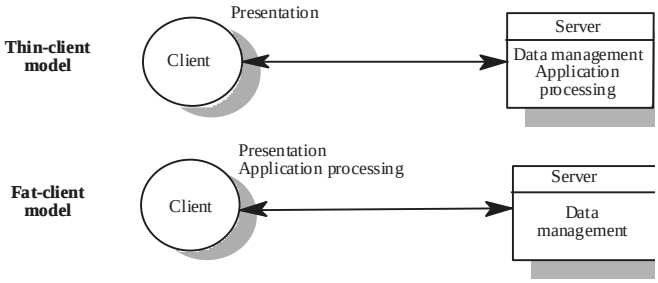
Distributing Layers to Processors

- Two-tier C/S architecture : the three layers are distributed between a server processor and a set of clients.
- Three-tier C/S architecture : the layers are distributed among two server processes / processors and a set of clients.
- Multi-tier C/S architectures : the layers are distributed among multiple server processes / processors (each associated with a separate database, for example) and a set of clients.

Two-tier Architectures: Thin and Fat Clients

- Thin-client model : the application logic and data management are implemented on the server; the client only handles the user interface.
- Fat-client model : the server is only responsible for data management; the client handles the application logic and the user interface.

Thin and Fat Clients



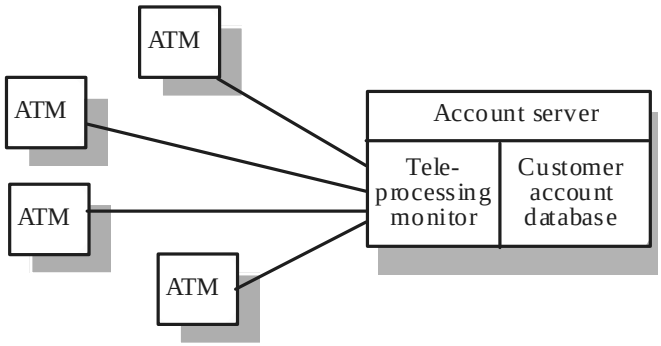
Thin-client Model

- Often used when centralized legacy systems evolve to a C/S architecture; the user interface is migrated to workstations or terminals and the legacy system acts as a server.
- Places a heavy processing load on both the server and the network; this is wasteful when clients are powerful workstations.

Fat-client Model

- More processing is delegated to the client as the application logic is executed locally.
- But system management is more complex, especially when application function changes and new logic must be installed on each client.

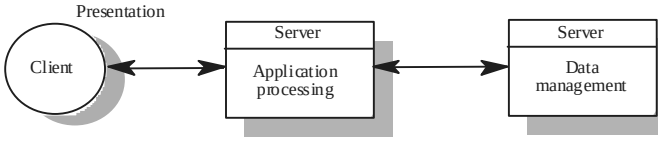
A Client-server ATM System



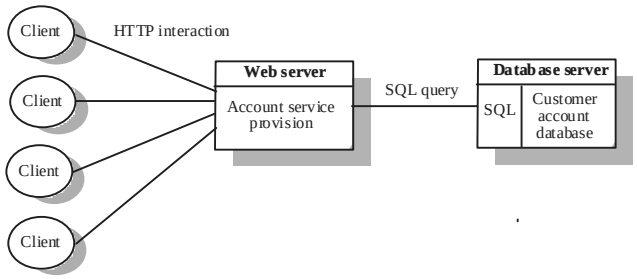
Three-tier Architectures

- Each application architecture layer may execute on a separate processor.
- Allows for better performance and scalability than a thin-client approach and is simpler to manage than a fat-client approach.

A 3-tier C/S Architecture



An Internet Banking System



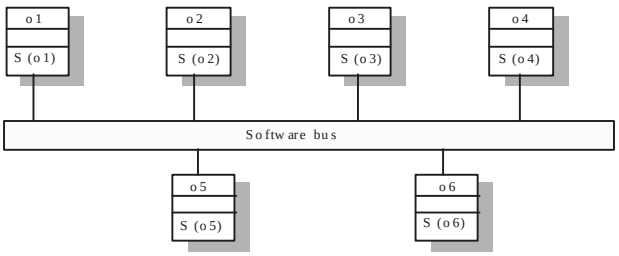
Use of C/S Architectures

Architecture	Applications
Two-tier C/S architecture with thin clients	Legacy system applications where separating application processing and data management is impractical Computationally-intensive applications such as compilers with little or no data management Data-intensive applications (browsing and querying) with little or no application processing.
Two-tier C/S architecture with fat clients	Applications where application processing is provided by COTS (e.g. Microsoft Excel) on the client Applications where computationally-intensive processing of data (e.g. data visualisation) is required. Applications with relatively stable end-user functionality used in an environment with well-established system management
Three-tier or multi-tier C/S architecture	Large scale applications with hundreds or thousands of clients Applications where both the data and the application are volatile. Applications where data from multiple sources are integrated

Distributed Object Architectures

- Eliminates the distinction between clients and servers.
- System components are objects that provide services to, and receive services from, other objects.
- Object communication is through middle-ware called an object request broker (effectively a software bus)

Distributed Object Architectures



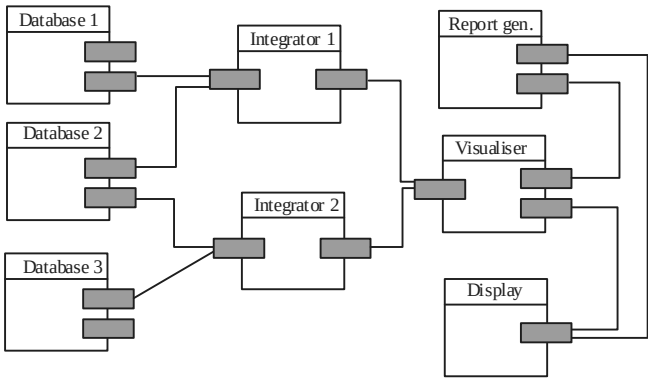
Advantages of Distributed Object Architectures

- Allows system designer to delay decisions on where and how services should be provided. (Service-providing objects may execute on any network node.)
- Very open architecture : allows new resources to be added as required.
- Flexible and scaleable.
- System is dynamically reconfigurable : objects can migrate across the network as required. (Thus improving performance.)

Uses of Distributed Object Architectures

- As a logical model for structuring and organizing a system solely in terms of services provided by a number of distributed objects. (E.g., a data mining system.)
- As a flexible means of implementing C/S systems. Both clients and servers are realised as distributed objects communicating through a software bus.

A Data Mining System



Disadvantages of Distributed Object Architectures

- Complex to design due to model generality and flexibility in service provision.
- C/S systems seem to be a more natural model for most systems. (They reflect many human service transactions.)

CORBA (Common Object Request Broker Architecture)

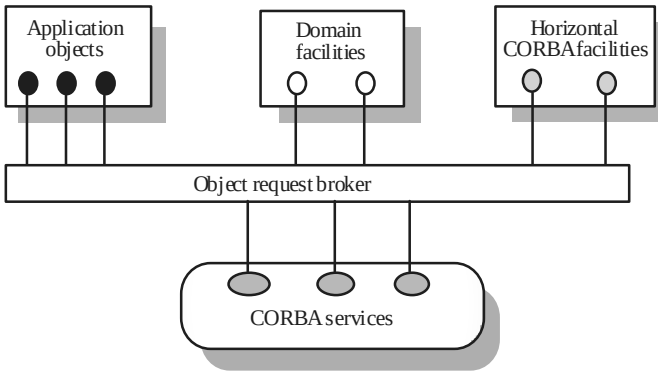
- International standards for an Object Request Broker (ORB): middleware to manage communications between distributed objects.
- Several implementation of CORBA are available (Unix and MS OS's).
- Defined by the Object Management Group (>500 companies, including Sun, HP, IBM).
- DCOM (Distributed Component Object Model) is an alternative standard developed and implemented by Microsoft.

Components of The OMG Vision of a Distributed Application

- Application objects designed and implemented for this application.

- Domain-specific objects defined by the OMG. (e.g., finance/ insurance, healthcare)
- Fundamental CORBA distributed computing services such as directories and security management.
- Horizontal facilities (such as user interface facilities) used in many different applications

COBRA Application Structure



Major Elements of the CORBA Standards

- An application object model where objects encapsulate state and have a well-defined, language-neutral interface defined in an IDL (interface definition language).
- An object request broker (ORB) that locates objects providing services, sends service requests, and returns results to requesters.
- A set of general object services of use to many distributed applications.
- A set of common components built on top of these services. (Task forces are currently defining these.)

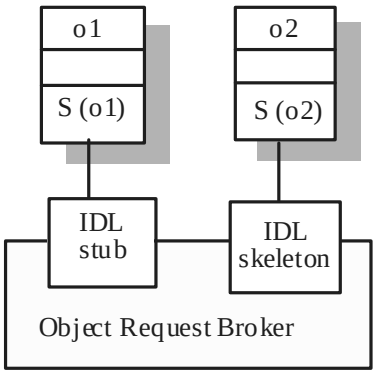
CORBA Objects

- Objects that provide services have IDL skeletons that link their interface to an implementation.
- Calling objects have IDL stubs for every object being called.
- Objects do not need to know the location or implementation details of other objects.

Object Request Broker (ORB)

- The ORB handles object communications. It knows of all objects in the system and their interfaces.
- The calling object binds an IDL stub that defines the interface of the called object.
- Calling this stub results in calls to the ORB, which then calls the required object through a published IDL skeleton that links the interface to the service implementation.

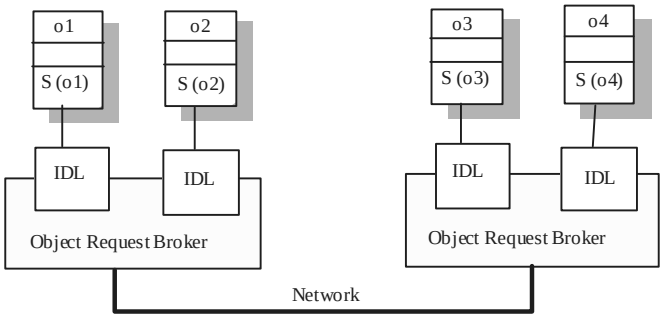
ORB-based Object Communications



Inter-ORB Communications

- ORBs handle communications between objects executing on the same machine.
- Inter-ORB communications are used for distributed object calls.
- CORBA supports ORB-to-ORB communication by providing all ORBs access to all IDL interface definitions and by implementing the OMG's standard Generic Inter-ORB Protocol (GIOP).

Inter-ORB Communications



Examples of General CORBA Services

- Naming and trading services : these allow objects to discover and refer to other objects on the network.
- Notification services : these allow objects to notify other objects that an event has occurred.
- Transaction services : these support atomic transactions and rollback on failure.

Key Points

- Almost all new large systems are distributed systems.
- Distributed systems support resource sharing, openness, concurrency, scalability, fault tolerance, and transparency.
- Client-server architectures involve services being delivered by servers to programs operating on clients.
- User interface software always runs on the client and data management on the server.
- In a distributed object architecture, there is no distinction between clients and servers.

- Distributed object systems require middle-ware to handle object communications.
- The CORBA standards are a set of middle-ware standards that support distributed object architectures.

Activity

Explain why distributed systems are inherently more scalable than centralized systems. What are the likely limits on the scalability of the system?

Activity

What is the fundamental difference between a fat-client and a thin-client approach to client-server systems development? Explain why the use of Java as an implementation language blurs the distinction between these approaches.

Activity

It is proposed to develop a system for stock information where dealers can access information about companies and can evaluate various investment scenarios using a simulation system. Different dealers use this simulation in different ways according to their experience and the type of stocks that they are dealing with. Suggest a client-server architecture for this system that shows where functionality is located justify the client server system model that you have chosen.

Activity

Distributed systems based on a client-server model have been developed since the 1980s but it is only recently that system architectures based on disrupted objects have been implemented. Suggest three reasons why this should be the case.

Activity

Explain why the use of distributed objects with an object request broker simplifies the implementation of scalable client-server systems. Illustrate your answer with an example.

Activity

How is the CORBA IDL used to support communications between objects that have been implemented in different programming languages? Explain why this approach may cause performance problems if there are radical differences between the languages used for object implementation.

Activity

What are the basic facilities that must be provided by an object request broker?

LESSON 19 AND 20:
OBJECT-ORIENTED DESIGN

Objectives

- To explain how a software design may be represented as a set of interacting objects that encapsulate their own state and operations.
- To describe the activities in the object-oriented design process
- To introduce various models used to describe an object-oriented design
- To show how the UML may be used to represent these models

Topics Covered

- Objects and object classes
- An object-oriented design process
- Design evolution

Characteristics of OOD

- Allows designers to think in terms of interacting objects that maintain their own state and provide operations on that state instead of a set of functions operating on shared data.
- Objects hide information about the representation of state and hence limit access to it.
- Objects may be distributed and may work sequentially or in parallel.

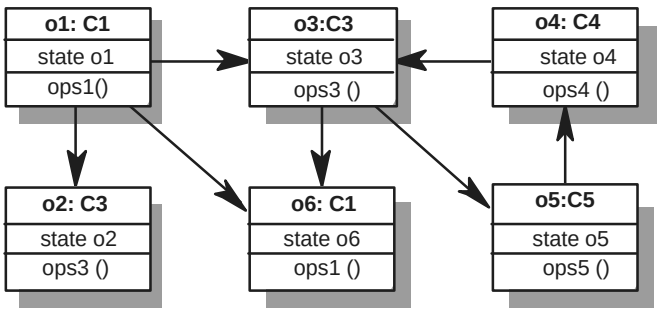
A design strategy based on "information hiding"…

- A useful definition of information hiding:

Potentially changeable design decisions are isolated (i.e., "hidden") to minimize the impact of change.

- David Parnas

Interacting Objects



Advantages of OOD

- Easier maintenance. Objects may be understood as stand-alone entities.
- Objects are appropriate reusable components.
- For some systems, there is an obvious mapping from real world entities to system objects.

Object-oriented Development

- OO Analysis: concerned with developing an object model of the application domain.
- OO Design: concerned with developing an object-oriented system model to implement requirements
- OO Programming: concerned with realising an OOD using an OO programming language such as Java or C++.

Objects and Object Classes

- Objects are entities with state and a defined set of operations on that state.

State is represented as a set of object attributes.

Operations provide services to other objects when requested.

- Object classes are templates for objects.

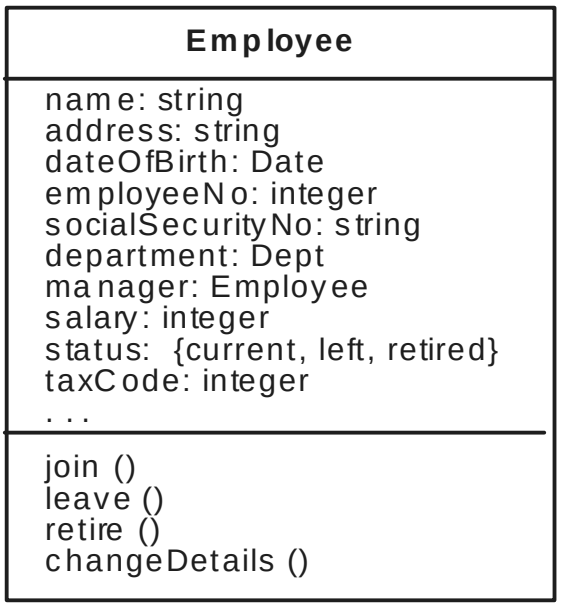
An object class definition includes declarations of all attributes and operations associated with an object of that class.

They may inherit attributes and services from other object classes.

The Unified Modeling Language

- Several different notations for OOD were proposed in the 1980s and 1990s. (Booch, Rumbaugh, Jacobson, Coad & Yourdon, Wirfs, …)
- UML is an integration of these notations.
- It describes a number of different models that may be produced during OO analysis and design (user view, structural view, behavioural view, implementation view, …)

Employee Object Class (UML)



Object Communication

- Conceptually, objects communicate by message passing.
- Messages include:

The name of the service requested,

A copy of the information required to carry out the service, and

the name of a holder for the result of the service.

- In practice, messages are often implemented by procedure calls

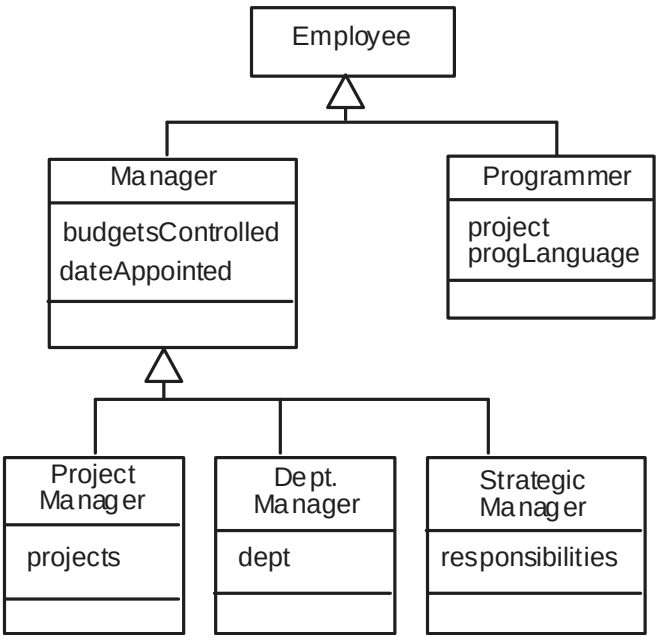
Message Examples

```
// Call a method associated with a buffer
// object that returns the next value
// in the buffer                    v = circularBuffer. Get ( );

// Call the method associated with a
// thermostat object that sets the
// temperature to be maintained     thermostat.setTemp (20);
```

Generalization and Inheritance

- Objects are members of classes, which define attribute types and operations.
- Classes may be arranged in a hierarchy where one class (a super-class) is a generalization of one or more other classes (sub-classes)
- A sub-class inherits the attributes and operations from its super class and may add new methods or attributes of its own.

A UML Generalisation Hierarchy



Advantages of Inheritance

- It is an abstraction mechanism, which may be used to classify entities.
- It is a reuse mechanism at both the design and the programming level.
- The inheritance graph is a source of organisational knowledge about domains and systems.

Problems With Inheritance

- Object classes are not self-contained (i.e., they cannot be understood without reference to their super-classes).
- Designers have a tendency to reuse the inheritance graph created during analysis. (Inheritance graphs of analysis, design and implementation have different functions.)

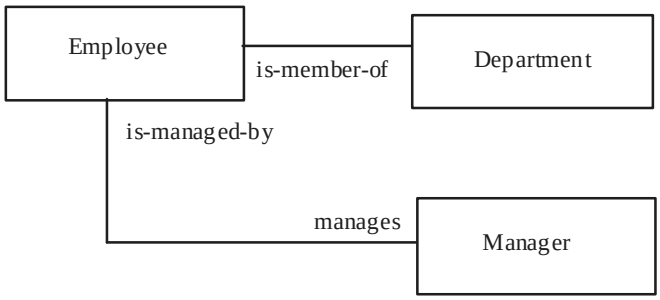
Inheritance and OOD

- Inheritance is a useful implementation concept, which allows reuse of attribute and operation definitions.
- Some feel that identifying an inheritance hierarchy or network is also a fundamental part of object-oriented design. (Obviously, this can only be implemented using an OOPL.)
- Others feel this places unnecessary restrictions on the implementation.
- Inheritance introduces complexity and this is undesirable, especially in critical systems.

UML Associations

- Objects and object classes participate in various types of relationships with other objects and object classes.
- In the UML, a generalized relationship is indicated by an association.
- Associations may be annotated with information that describes their nature.
- Associations can be used to indicate that an attribute of an object is an associated object or that a method relies on an associated object.

An Association Model



Concurrent Objects

- The nature of objects as self-contained entities make them well suited for con-current implementation.
- The message-passing model of object communication can be implemented directly if objects are running on separate processors in a distributed system.

Concurrent object implementation: servers and active objects

- Servers (Passive objects): implemented as parallel processes with entry points corresponding to object operations. If no

calls are made to it, the object suspends itself and waits for further requests for service.

- Active objects: implemented as parallel processes and the internal object state may be changed by the object itself and not simply by external calls.

Example: An Active Transponder Object

- A transponder object broadcasts an aircraft's position.
- The object periodically updates the position by triangulation from satellites.

An Object-oriented Design Process

- Define the context and modes of use of the system.
- Design the system architecture.
- Identify the principal system objects.
- Develop design models (static and dynamic).
- Specify object interfaces.

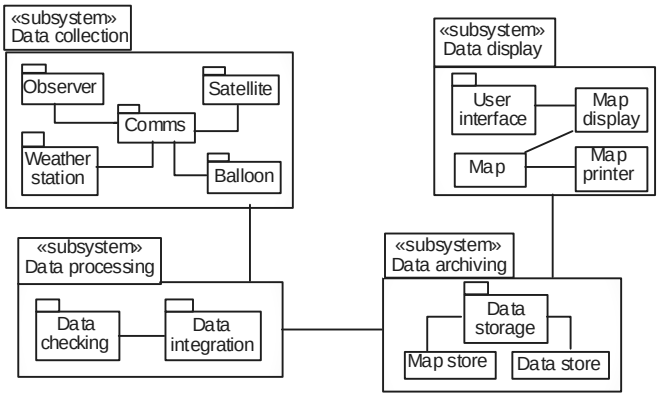
Weather System Description

- A weather data collection system is required to generate weather maps on a regular basis using data collected from remote, unattended weather stations and other data sources such as weather observers, balloons and satellites. Weather stations transmit their data to the area computer in response to a request from that machine.
- The area computer validates the collected data and integrates it with the data from different sources. The integrated data is archived and, using data from this archive and a digitised map database a set of local weather maps is created. Maps may be printed for distribution on a special-purpose map printer or may be displayed in a number of different formats.
- A weather station is a package of software-controlled instruments, which collects data, performs some data processing and transmits this data for further processing. The instruments include air and ground thermometers, an anemometer, a wind vane, a barometer and a rain gauge. Data is collected every five minutes.
- When a command is issued to transmit the weather data, the weather station processes and summarises the collected data. The summarised data is transmitted to the mapping computer when a request is received.

1.Define system context and modes of use

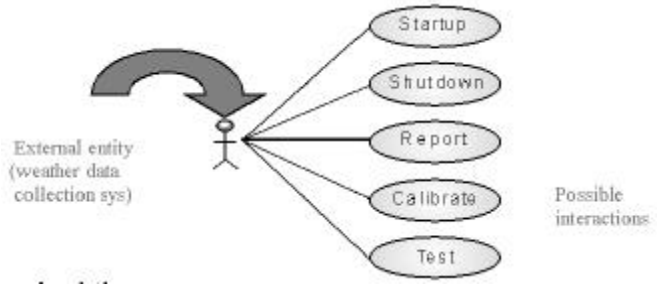
- Goal: develop an understanding of the relationships between the software being designed and its external environment.
- System context: a static model that describes other systems in the environment.
- The context of the weather station is illustrated below using UML packages.

Context of Weather Station



- Modes of system use : a dynamic model that describes how the system will interact with its environment.
- Modes of weather station use are illustrated below using a UML use-case model.

Use-cases for the Weather Station



Use-case Description

System	Weather station
Use-case	Report
Actors	Weather data collection system, Weather station
Data	The weather station sends a summary of the weather data that has been collected from the instruments in the collection period to the weather data collection system. The data sent are the maximum minimum and average ground and air temperatures, the maximum, minimum and average air pressures, the maximum, minimum and average wind speeds, the total rainfall and the wind direction as sampled at 5 minute intervals.
Stimulus	The weather data collection system establishes a modem link with the weather station and requests transmission of the data.
Response	The summarised data is sent to the weather data collection system
Comments	Weather stations are usually asked to report once per hour but this frequency may differ from one station to the other and may be modified in future.

2. Design System Architecture

- A layered architecture is appropriate for the weather station:

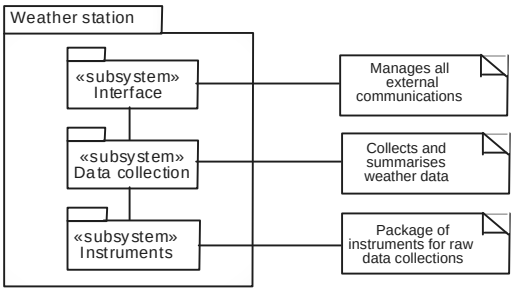
Interface layer : for handling communications

Data collection layer : for managing instruments

Instruments layer : for collecting data

- Rule of Thumb: There should be no more than 7 entities in an architectural model.

Weather Station Architecture



UML "nested packages" *UML annotations*

3. Identify Principal System Objects

- Identifying objects (or object classes) is the most difficult part OO design.
- There is no "magic formula" – it relies on the skill, experience, and domain knowledge of system designers
- An iterative process – you are unlikely to get it right the first time.

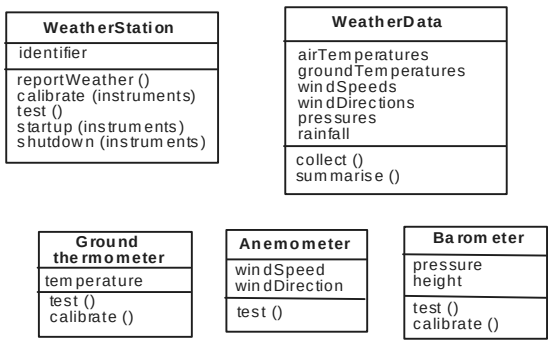
Approaches to Object Identification

- Use a grammatical approach based on a natural language description of the system (Abbott's heuristic).
- Associate objects with tangible things in the application domain (e.g. devices).
- Use a behavioural approach: identify objects based on what participates in what behaviour.
- Use scenario-based analysis. The objects, attributes and methods in each scenario are identified.
- Use an information-hiding based approach. Identify potentially change-able design decisions and isolate these in separate objects.

Weather Station Object Classes

- Weather station : interface of the weather station to its environment. It reflects interactions identified in the use-case model.
- Weather data : encapsulates summarised data from the instruments.
- Ground thermometer, Anemometer, Barometer : application domain "hardware" objects related to the instruments in the system

Weather Station Object Classes



Other Objects And Object Refinement

- Use domain knowledge to identify more objects, operations, and attributes.

Weather stations should have a unique identifier.

Weather stations are remotely situated so instrument failures have to be reported automatically. Therefore, attributes and operations for self checking are required.

- Active or passive objects?

Instrument objects are passive and collect data on request rather than autonomously. This introduces flexibility (how?) at the expense of controller processing time.

Are any active objects required?

4. Develop Design Models

- Design models show the relationships among objects and object classes.
- Static models describe the static structure of the system in terms of object and object class relationships.
- Dynamic models describe the dynamic interactions among objects.

Examples of Design Models

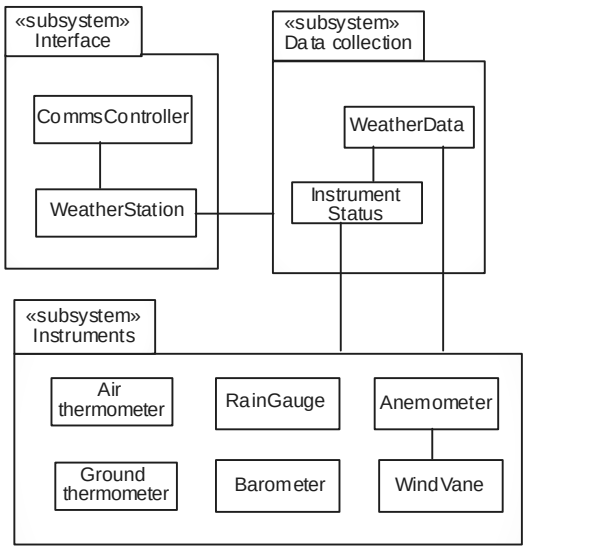
- Sub-system models show logical groupings of objects into coherent sub-systems. (static)
- Sequence models show the sequence of object interactions associated with system uses. (dynamic)
- State machine models show how individual objects change their state in response to events. (dynamic)
- Other models include use-case models, aggregation models, generalisation (inheritance) models, etc.

Subsystem Models

- In the UML, these are shown using packages, an encapsulation construct.
- This is a logical model – the actual organization of objects in the system as implemented may be different.

Weather Station Subsystems

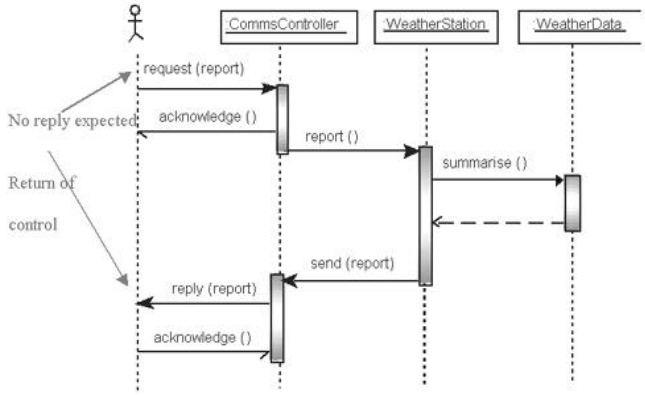
-Annotations



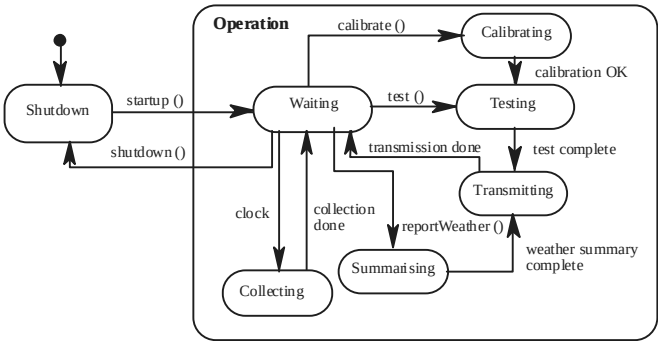
Sequence Models

- Objects are arranged horizontally across the top.
- Time is represented vertically; models are read top to bottom.
- Interactions are represented by labelled arrows - different styles of arrows represent different types of interaction.
- A thin rectangle in an object lifeline represents the time when the object is the controlling object in the system.

Data collection sequence



Weather Station State Machine Model



5. Object Interface Specification

- Designers should avoid revealing data representation information in their interface design. (operations access and update data)
- Objects may have several logical interfaces, which are viewpoints on the methods provided. (supported directly in Java)
- The UML uses class diagrams for interface specification but pseudocode may also be used.

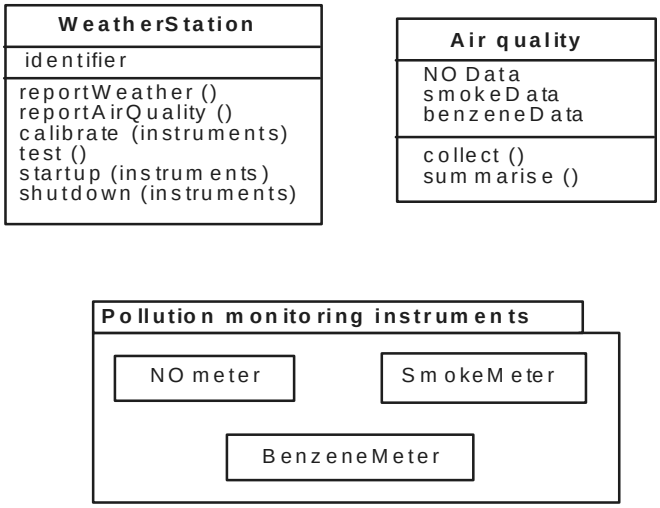
Design Evolution

- Hiding information in objects means that changes made to an object do not affect other objects in an unpredictable way.
- Assume pollution-monitoring facilities are to be added to weather stations.
- Pollution readings are transmitted with weather data.

Changes Required

- Add an object class called “Air quality” as part of Weather Station
- Add an operation reportAirQuality to WeatherStation. Modify the control software to collect pollution readings
- Add objects representing pollution monitoring instruments.

Pollution Monitoring



Key Points

- OOD results in design components with their own private state and operations.
- Objects should have constructor and inspection operations. They provide services to other objects.
- Objects may be implemented sequentially or concurrently.
- The Unified Modeling Language provides different notations for defining different object models.
- A range of different models may be produced during an object-oriented design process. These include static and dynamic system models
- Object interfaces should be defined precisely.
- Object-oriented design simplifies system evolution.

Activity

Explain why adopting an approach to design that is based on loosely coupled objects that hide information about their representation should lead to a design which may be readily modified.

Activity

Using examples, explain the difference between an object and an object class.

Activity

Under what circumstances might it be appropriate to develop a design where objects execute concurrently?

Activity

Using the UML graphical notation for object classes, design the following object classes identifying attributes and operations. Use your own experience to decide on the attributes and operations that should be associated with these objects:

- A telephone:
- A printer for a personal computer;
- A personal stereo system;
- A bank account;
- A library catalogue.

Activity

Develop the design of the weather station to show the interaction between the data collection sub- system and the instruments that collect weather data. Use sequence charts to show this interaction.

Activity

Identify possible objects in the following systems and develop an object oriented design for them. You may make any reasonable assumptions about the systems when deriving the design.

- A group diary and time management system is intended to support the timetabling of meetings and appointments across a group of co-workers. When an appointment is to be made which involves a number of people, the system finds a common slot in each of their diaries and arranges the appointment for that time. If no common slots are available, it interacts with the users to rearrange their personal diaries to make room fort the appointment.
- A petrol (gas) station is to be set up for fully automated operation. Derivers swipe their credit card through a reader connected to the pump; the card is verified by communication with a credit company computer and a fuel limit established. The driver may then take the fuel required when fuel delivery is complete and the pump hose is returned to its holster, the driver's credit card account is debited with the cost to the furl taken. The credit card is returned after debiting. If the card is invalid, it is returned buy the pump before fuel is dispensed.

Activity

Draw a sequence diagram showing the interactions of objects in a group diary system when a group of people arrange a meeting.

LESSON 21 AND 22:
REAL-TIME SOFTWARE DESIGN

Designing Embedded Software Systems Whose Behaviour is Subject to Timing Constraints

Objectives

- To explain the concept of a real-time system and why these systems are usually implemented as concurrent processes
- To describe a design process for real-time systems
- To explain the role of a real-time executive
- To introduce generic architectures for monitoring and control and data acquisition systems

Topics Covered

- Systems design
- Real-time executives
- Monitoring and control systems
- Data acquisition systems

Real-time Systems

- Systems, which monitor and control their environment
- Inevitably associated with hardware devices

Sensors: Collect data from the system environment

Actuators: Change (in some way) the system's environment

- Time is critical. Real-time systems MUST respond within specified times

Definition

- A real-time system is a software system where the correct functioning of the system depends on the results produced by the system and the time at which these results are produced
- A 'soft' real-time system is a system whose operation is degraded if results are not produced according to the specified timing requirements
- A 'hard' real-time system is a system whose operation is incorrect if results are not produced according to the timing specification

Stimulus/Response Systems

- Given a stimulus, the system must produce a response within a specified time
- Periodic stimuli. Stimuli, which occur at predictable time intervals

For example, a temperature sensor may be polled 10 times per second

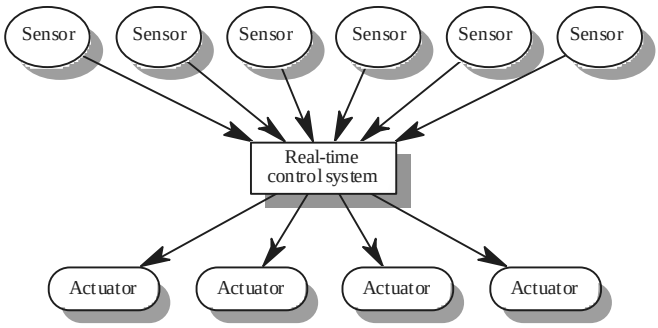
- A periodic stimuli. Stimuli, which occur at unpredictable times

For example, a system power failure may trigger an interrupt, which must be processed by the system

Architectural Considerations

- Because of the need to respond to timing demands made by different stimuli/responses, the system architecture must allow for fast switching between stimulus handlers
- Timing demands of different stimuli are different so a simple sequential loop is not usually adequate
- Real-time systems are usually designed as cooperating processes with a real-time executive controlling these processes

A Real-time System Model



System Elements

- Sensors control processes

Collect information from sensors. May buffer information collected in response to a sensor stimulus

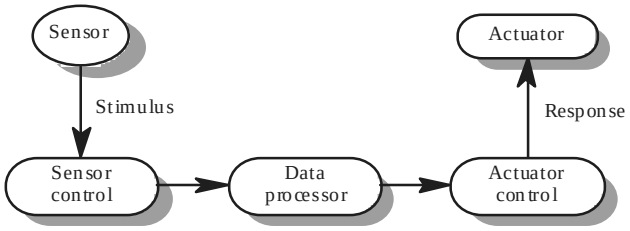
- Data processor

Carries out processing of collected information and computes the system response

- Actuator control

Generates control signals for the actuator

Sensor/Actuator Processes

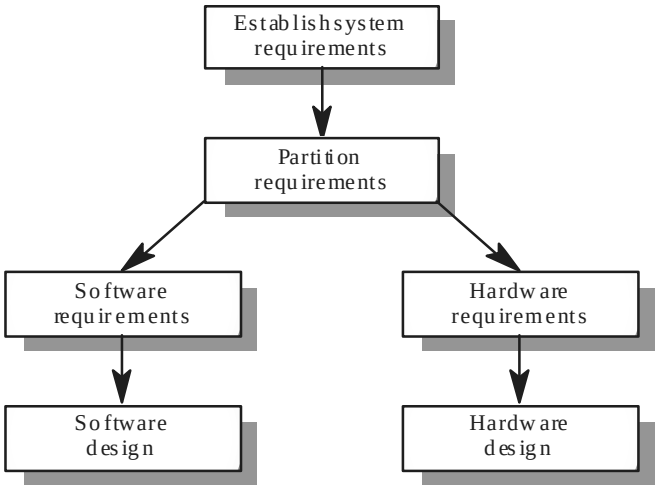


System Design

- Design both the hardware and the software associated with system. Partition functions to either hardware or software
- Design decisions should be made on the basis on non-functional system requirements

- Hardware delivers better performance but potentially longer development and less scope for change

Hardware and Software Design



R-t Systems Design Process

- Identify the stimuli to be processed and the required responses to these stimuli
- For each stimulus and response, identify the timing constraints
- Aggregate the stimulus and response processing into concurrent processes.
- A process may be associated with each class of stimulus and response
- Design algorithms to process each class of stimulus and response. These must meet the given timing requirements
- Design a scheduling system, which will ensure that processes are started in time to meet their deadlines
- Integrate using a real-time executive or operating system

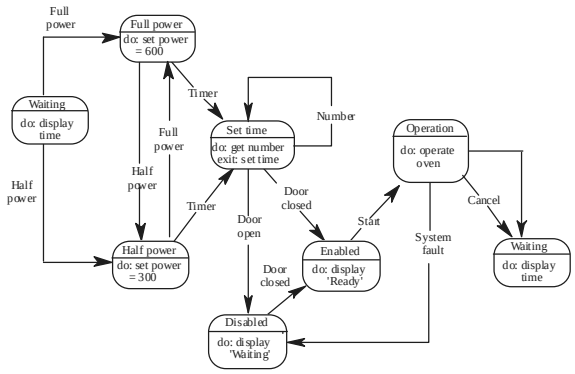
Timing Constraints

- May require extensive simulation and experiment to ensure that these are met by the system
- May mean that certain design strategies such as object-oriented design cannot be used because of the additional overhead involved
- May mean that low-level programming language features have to be used for performance reasons

State Machine Modelling

- The effect of a stimulus in a real-time system may trigger a transition from one state to another.
- Finite state machines can be used for modelling real-time systems.
- However, FSM models lack structure. Even simple systems can have a complex model.
- The UML includes notations for defining state machine models

Microwave Oven State Machine



Real-time Programming

- Hard-real time systems may have to programmed in assembly language to ensure that deadlines are met
- Languages such as C allow efficient programs to be written but do not have constructs to support concurrency or shared resource management
- Ada as a language designed to support real-time systems design so includes a general-purpose concurrency mechanism

Java As A Real-time Language

- Java supports lightweight concurrency (threads and synchronized methods) and can be used for some soft real-time systems
- Java 2.0 is not suitable for hard RT programming or programming where precise control of timing is required

Not possible to specify thread execution time

Uncontrollable garbage collection

Not possible to discover queue sizes for shared resources

Variable virtual machine implementation

Not possible to do space or timing analysis

Real-time Executives

- Real-time executives are specialised operating systems, which manage the processes in the RTS
- Responsible for process management and resource (processor and memory) allocation
- May be based on a standard RTE kernel which is used unchanged or modified for a particular application
- Does not include facilities such as file management

Executive Components

- Real-time clock

Provides information for process scheduling.

- Interrupt handler

Manages aperiodic requests for service.

- Scheduler

Chooses the next process to be run.

- Resource manager

Allocates memory and processor resources.

- Despatcher

Starts process execution.

Non-stop System Components

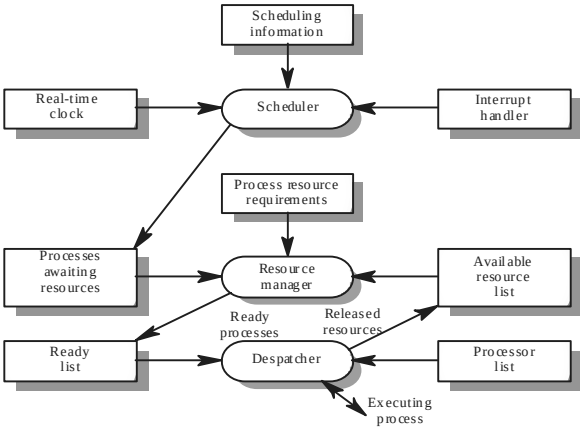
- Configuration manager

Responsible for the dynamic reconfiguration of the system software and hardware. Hardware modules may be replaced and software upgraded without stopping the systems

- Fault manager

Responsible for detecting software and hardware faults and taking appropriate actions (e.g. switching to backup disks) to ensure that the system continues in operation

Real-time Executive Components



Process Priority

- The processing of some types of stimuli must sometimes take priority
- Interrupt level priority. Highest priority, which is allocated to processes requiring a very fast response
- Clock level priority. Allocated to periodic processes
- Within these, further levels of priority may be assigned

Interrupt Servicing

- Control is transferred automatically to a pre-determined memory location
- This location contains an instruction to jump to an interrupt service routine
- Further interrupts are disabled, the interrupt serviced and control returned to the interrupted process
- Interrupt service routines MUST be short, simple and fast

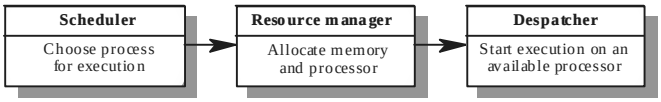
Periodic Process Servicing

- In most real-time systems, there will be several classes of periodic process, each with different periods (the time between executions), execution times and deadlines (the time by which processing must be completed)
- The real-time clock ticks periodically and each tick causes an interrupt which schedules the process manager for periodic processes
- The process manager selects a process, which is ready for execution

Process Management

- Concerned with managing the set of concurrent processes
- Periodic processes are executed at pre-specified time intervals
- The executive uses the real-time clock to determine when to execute a process
- Process period - time between executions
- Process deadline - the time by which processing must be complete

RTE Process Management



Process Switching

- The scheduler chooses the next process to be executed by the processor. This depends on a scheduling strategy, which may take the process priority into account
- The resource manager allocates memory and a processor for the process to be executed
- The despatcher takes the process from ready list, loads it onto a processor and starts execution

Scheduling Strategies

- Non pre-emptive scheduling

Once a process has been scheduled for execution, it runs to completion or until it is blocked for some reason (e.g. waiting for I/O)

- Pre-emptive scheduling

The execution of executing processes may be stopped if a higher priority process requires service

- Scheduling algorithms

Round-robin

Rate monotonic

Shortest deadline first

Monitoring and Control Systems

- Important class of real-time systems
- Continuously check sensors and take actions depending on sensor values
- Monitoring systems examine sensors and report their results
- Control systems take sensor values and control hardware actuators

Burglar Alarm System

- A system is required to monitor sensors on doors and windows to detect the presence of intruders in a building
- When a sensor indicates a break-in, the system switches on lights around the area and calls police automatically
- Sensors

Movement detectors, window sensors, door sensors.

50 window sensors, 30 door sensors and 200 movement detectors

Voltage drop sensor

- Actions

When an intruder is detected, police are called automatically.

Lights are switched on in rooms with active sensors.

An audible alarm is switched on.

The system switches automatically to backup power when a voltage drop is detected.

The R-T System Design Process

- Identify stimuli and associated responses
- Define the timing constraints associated with each stimulus and response
- Allocate system functions to concurrent processes
- Design algorithms for stimulus processing and response generation
- Design a scheduling system, which ensures that processes will always be scheduled to meet their deadlines

Stimuli to be Processed

- Power failure

Generated aperiodically by a circuit monitor. When received, the system must switch to backup power within 50ms

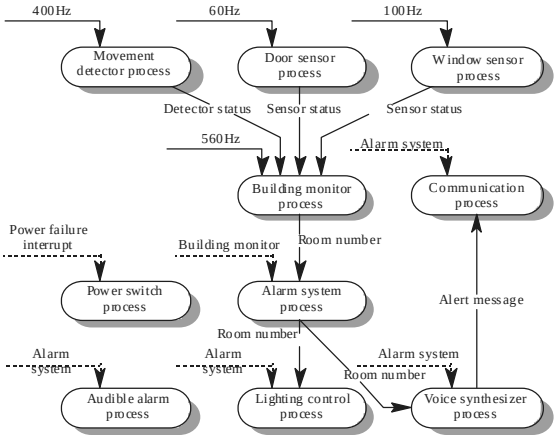
- Intruder alarm

Stimulus generated by system sensors. Response is to call the police, switch on building lights and the audible alarm

Timing Requirements

Stimulus/Response	Timing requirements
Power fail interrupt	The switch to backup power must be completed within a deadline of 50 ms.
Door alarm	Each door alarm should be polled twice per second.
Window alarm	Each window alarm should be polled twice per second.
Movement detector	Each movement detector should be polled twice per second.
Audible alarm	The audible alarm should be switched on within 1/2 second of an alarm being raised by a sensor.
Lights switch	The lights should be switched on within 1/2 second of an alarm being raised by a sensor.
Communications	The call to the police should be started within 2 seconds of an alarm being raised by a sensor.
Voice synthesiser	A synthesised message should be available within 4 seconds of an alarm being raised by a sensor.

Process Architecture



Building Monitor Process 1

```
    // See http://www.software-engin.com/ for links to the complete Java code for this
// example

    class BuildingMonitor extends Thread {

        BuildingSensor win, door, move ;

        Siren     siren = new Siren () ;
        Lights    lights = new Lights () ;
        Synthesizer synthesizer = new Synthesizer () ;
        DoorSensors doors = new DoorSensors (30) ;
        WindowSensors   windows = new WindowSensors (50) ;
        MovementSensors movements = new MovementSensors (200) ;
        PowerMonitor pm = new PowerMonitor () ;

        BuildingMonitor()
        {
            // initialise all the sensors and start the processes
            siren.start () ; lights.start () ;
            synthesizer.start () ; windows.start () ;
            doors.start () ; movements.start () ; pm.start () ;

        }
```

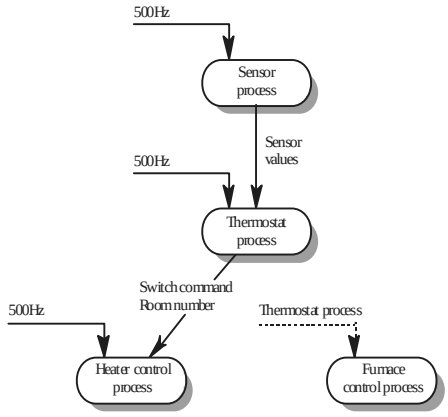
Building Monitor Process 2

```
        public void run ()
        {
            int room = 0 ;
            while (true)
            {
                // poll the movement sensors at least twice per second (400 Hz)
                move = movements.getVal () ;
                // poll the window sensors at least twice/second (100 Hz)
                win = windows.getVal () ;
                // poll the door sensors at least twice per second (60 Hz)
                door = doors.getVal () ;
                if (move.sensorVal == 1 | door.sensorVal == 1 | win.sensorVal == 1)
                    {
                        // a sensor has indicated an intruder
                        if (move.sensorVal == 1)      room = move.room ;
                        if (door.sensorVal == 1)      room = door.room ;
                        if (win.sensorVal == 1 )              room = win.room ;

                        lights.on (room) ; siren.on () ; synthesizer.on (room) ;
                        break ;
                    }
            }
            lights.shutdown () ; siren.shutdown () ; synthesizer.shutdown () ;
            windows.shutdown () ; doors.shutdown () ; movements.shutdown () ;

    } // run
} //BuildingMonitor
```

Control Systems

- A burglar alarm system is primarily a monitoring system. It collects data from sensors but no real-time actuator control
- Control systems are similar but, in response to sensor values, the system sends control signals to actuators
- An example of a monitoring and control system is a system, which monitors temperature and switches heaters on and off

A Temperature Control System



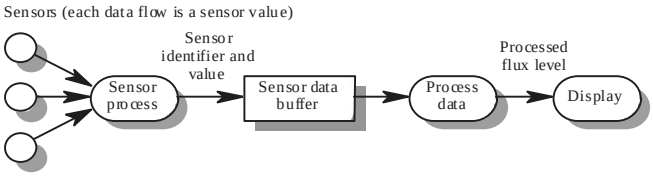
Data Acquisition Systems

- Collect data from sensors for subsequent processing and analysis.
- Data collection processes and processing processes may have different periods and deadlines.
- Data collection may be faster than processing e.g. collecting information about an explosion.
- Circular or ring buffers are a mechanism for smoothing speed differences.

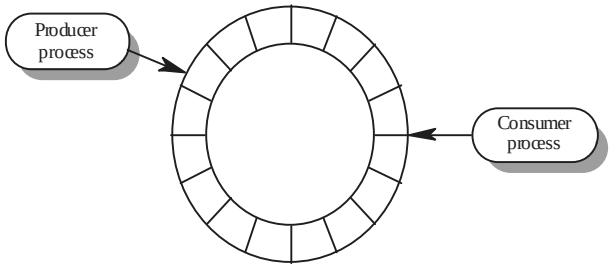
Reactor Data Collection

- A system collects data from a set of sensors monitoring the neutron flux from a nuclear reactor.
- Flux data is placed in a ring buffer for later processing.
- The ring buffer is itself implemented as a concurrent process so that the collection and processing processes may be synchronized.

Reactor Flux Monitoring



A Ring Buffer



Mutual Exclusion

- Producer processes collect data and add it to the buffer. Consumer processes take data from the buffer and make elements available
- Producer and consumer processes must be mutually excluded from accessing the same element.
- The buffer must stop producer processes adding information to a full buffer and consumer processes trying to take information from an empty buffer.

Java Implementation of a Ring Buffer 1

```
class CircularBuffer
{
    int bufsize ;
    SensorRecord [] store ;
    int numberOfEntries = 0 ;
    int front = 0, back = 0 ;

    CircularBuffer (int n) {
        bufsize = n ;
        store = new SensorRecord [bufsize] ;
    } // CircularBuffer

    synchronized void put (SensorRecord rec ) throws InterruptedException
    {
        if ( numberOfEntries == bufsize)
            wait () ;
        store [back] = new SensorRecord (rec.sensorId, rec.sensorVal) ;
        back = back + 1 ;
        if (back == bufsize)
            back = 0 ;
        numberOfEntries = numberOfEntries + 1 ;
        notify () ;
    } // put
```

Java Implementation of a Ring Buffer 2

```
    synchronized SensorRecord get () throws InterruptedException
    {
        SensorRecord result = new SensorRecord (-1, -1) ;
        if (numberOfEntries == 0)
                wait () ;
        result = store [front] ;
        front = front + 1 ;
        if (front == bufsize)
            front = 0 ;
        numberOfEntries = numberOfEntries - 1 ;
        notify () ;
        return result ;
    } // get
} // CircularBuffer
```

Key Points

- Real-time system correctness depends not just on what the system does but also on how fast it reacts
- A general RT system model involves associating processes with sensors and actuators
- Real-time systems architectures are usually designed as a number of concurrent processes
- Real-time executives are responsible for process and resource management.
- Monitoring and control systems poll sensors and send control signal to actuators
- Data acquisition systems are usually organised according to a producer consumer model

- Java has facilities for supporting concurrency but is not suitable for the development of time-critical systems

Activity

Using examples, explain why real time systems usually have to be implemented using processes.

Activity

Explain why an object oriented approach to software development may not be suitable for real time systems.

Activity

Draw state machine models of the control software for the following systems:

- An automatic washing machine, which has different programs for different types of clothes.
- The software for a compact disc player.
- A telephone answering machine, which records incoming messages and displays the number of accepted messages on an LED display. The system should allow the telephone owner to dial in, type a sequence of numbers (identified as tones) and have the recorded messages replayed over the phone.
- A drinks vending machine, which can dispense coffee with and without milk and sugar. The user deposits a coin and makes his or her selection by pressing a button on the machine. This causes a cup with powdered coffee to be output. The user places this cup under a tap, presses another button and hot eater is dispensed.

Activity

Discuss the strengths and weaknesses of Java as a programming language for real time systems.

Activity

You are asked to work on a real-time development project for a military application but have no previous experience of projects in that domain. Discuss what you, as a professional software engineer, should do before starting work on the project.

Notes:

LESSON 23:
DESIGN WITH REUSE

Objectives

- To explain the benefits and some potential problems with software reuse.
- To describe different types of reusable elements and processes for reuse.
- To introduce application families as a route to reuse.
- To describe design patterns as high-level abstractions that promote reuse.

Topics Covered

- Component-based development
- Application families
- Design patterns

Reuse-based Software Engineering

- In most engineering disciplines, systems are routinely designed by composing elements that have been used in other systems.
- This has not been true in SE, but to reduce risks and accelerate development, it is now recognized that we need to adopt design processes based on systematic reuse.

Software Reuse Practice

- Application system reuse : widely practised as software systems are implemented as application families. COTS reuse is becoming increasingly common.
- Component reuse : now seen as the key to effective and widespread reuse through Component-Based Software Engineering (CBSE). However, it is still relatively immature.
- Function reuse : libraries of reusable functions have been common for 40 years.

Benefits of Reuse

- Increased reliability : when reused elements have been tried and tested in a variety of working systems.
- Reduced process risk : less uncertainty of cost compared to new development.
- More effective use of specialists : re-use elements instead of experts.
- Standards compliance : when standards are embedded in reusable elements.
- Accelerated development : reduced development and validation time.

Requirements for Design with Reuse

- Must be possible to find appropriate reusable elements.
- Must be confident that the elements will be reliable and will behave as specified.
- Elements must be documented so that they can be understood and, when necessary, modified.

Reuse Problems

- Increased maintenance costs – especially if source code / documentation absent.
- Lacks of tool support – CASE toolsets do not support development with reuse.
- Not-invented-here syndrome
- Repositories of reusable elements – techniques for classifying, cataloguing, and retrieving elements are immature.
- Finding, understanding, and adapting reusable elements takes time.

Component-based Development

- Component-Based Software Engineering (CBSE) is a development approach based on systematic reuse.
- CBSE emerged in the late 1990's due to failure of OO development to lead to extensive reuse.
- Components are designed to be general service providers.

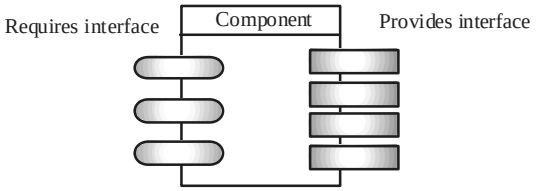
Critical Characteristics of a Reusable Component

- An independent executable entity: source code is typically not available so the component is not compiled with other system elements.
- All interactions are through a published (2-part) interface : internal state is never exposed.

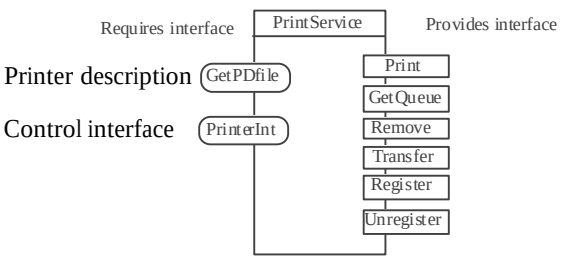
Component Interface

- "Provides interface" : defines the services that are provided by the component to other system elements.
- "Requires interface" : defines the services that must be made available to the component by other system elements in order to operate.

Component Interfaces



Printing Services Component



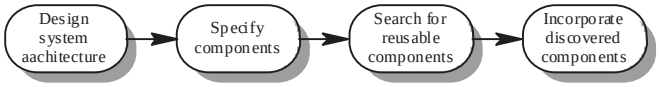
Component Abstraction Levels

- Functional abstraction : implements a single function (e.g., square root)
- Casual groupings : loosely related entities such as data declarations and functions
- Data abstractions : a data abstraction or object class
- Cluster abstractions : related object classes that work together
- System abstraction : an entire, self-contained system (e.g., MS Excel)

CBSE Processes

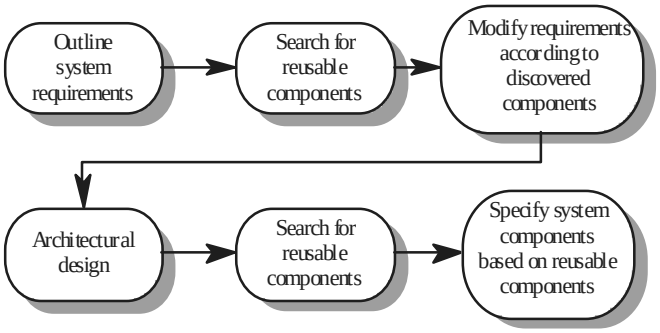
- Component-based reuse may be opportunistic, or it may drive the development process.
- In reuse-driven development, system requirements are modified to reflect the available components.
- CBSE often involves an evolutionary development process with components being "glued together" using a scripting language. (e.g., Unix shell, Visual Basic, TCL/TK)

An Opportunistic Reuse Process



the "we might get lucky" approach

Reuse-driven Development


Outline system requirements
Search for reusable components
Modify requirements according to discovered components
Architectural design
Search for reusable components
Specify system components based on reusable components

CBSE Problems

- Component incompatibilities : may mean that cost and schedule savings are less than expected.
- Finding and understanding components : repositories and tool support are lacking.
- Managing evolution as requirements change : source code is typically not available. ("waiting for the next release")

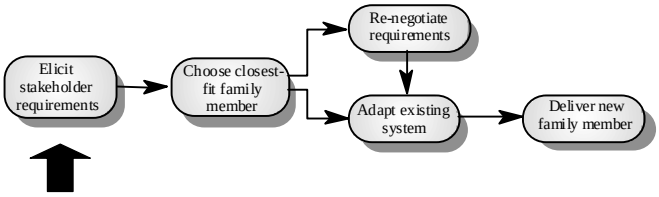
Application Families

- An application family or product line is a related set of applications that has a common, domain-specific architecture.
- The common core of the application family is reused each time a new application is required.
- Each specific application is specialized in some way.

Application Family Specialization

- Platform specialization : different versions of the application are developed for different platforms.
- Configuration specialization : different versions of the application are created to handle different peripheral devices.
- Functional specialization : different versions of the application are created for customers with different requirements.

Family Member Development



Use existing family member as prototype

Design Patterns (Chris Alexander, Mid-70's)

- A way of reusing "accumulated knowledge and wisdom" about a problem and its solution.
- A design pattern is a description of some problem and the essence of its solution.
- Should be sufficiently abstract to be reusable in different contexts.
- Often utilize OO characteristics such as inheritance and polymorphism.

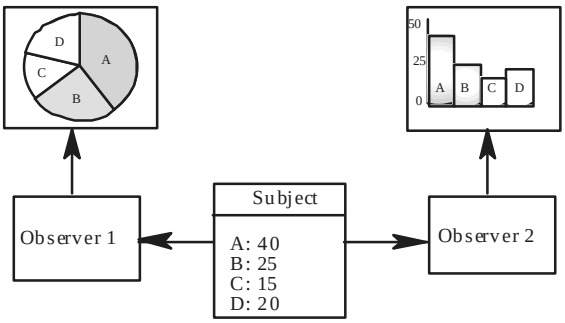
Pattern Elements (Gamma, '95)

- Name: a meaningful pattern identifier
- Problem description
- Solution description: a template for a design solution that can be instantiated in different operational contexts (often illustrated graphically)
- Consequences: the results and trade-offs of applying the pattern (analysis and experience)

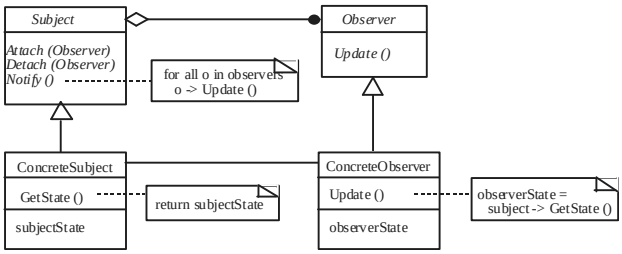
The Observer Pattern (Details: P. 323)

- Name: Observer
- Description: Separates the display of object state from the object itself.
- Problem description: Used when multiple displays of state are needed.
- Solution description: See UML description
- Consequences: Optimisations to enhance display performance are impractical.

Multiple Displays



The Observer Pattern



Key Points

- Design with reuse involves designing software around existing examples of good design and making use of existing software elements.
- Advantages are lower costs, faster software development, and lower risks.
- CBSE relies on black-box components with defined requires- and provides- interfaces.
- Software components for reuse should be independent, reflect stable domain abstractions, and provide access to state through interface operations.
- COTS product reuse is concerned with the reuse of large-scale, off-the-shelf systems.
- Application families are related applications that have a common, domain-specific architecture.
- Design patterns are high-level abstractions that document successful design solutions.

Activity

What are the major technical and non-technical factors which hinder software reuse? Form your own experience, do you reuse much software? If not, why not?

Activity

Explain why the savings in cost form reusing existing software is not simple proportional to the size of the components that are reused.

Activity

Give four circumstances where you might recommend against software reuse.

Activity

Suggest possible requires and provides interfaces for the following components:

- A component implementing a bank account.
- A component implementing a language-independent keyboard. Keyboards in different countries have different key organizations and different character sets.

Activity

What is the difference between an application framework and a COTS product as for as reuse is concerned? Why is it sometimes easier to reuse a COTS product than an application framework?

Activity

Why are patterns an effective form of design reuse? What are the disadvantages to this approach to reuse?

Activity

The reuse of software raises a number of copyright and intellectual property issues. If a customer pays a software contractor to develop some system, who has the right to reuse the developed code? Does the software contractor have the right to use that code as a basis for a generic component? What payment mechanisms might be used to reimburse providers of reusable components? Discuss these issues and other ethical issues associated with the reuse of software.

LESSON 24 AND 25:
USER INTERFACE DESIGN

Designing Effective Interfaces for Software Systems

Objectives

- To suggest some general design principles for user interface design
- To explain different interaction styles
- To introduce styles of information presentation
- To describe the user support which should be built-in to user interfaces
- To introduce usability attributes and system approaches to system evaluation

Topics Covered

- User interface design principles
- User interaction
- Information presentation
- User support
- Interface evaluation

The User Interface

- System users often judge a system by its interface rather than its functionality
- A poorly designed interface can cause a user to make catastrophic errors
- Poor user interface design is the reason why so many software systems are never used

Graphical User Interfaces

- Most users of business systems interact with these systems through graphical interfaces although, in some cases, legacy text-based interfaces are still used

GUI Characteristics

Characteristic	Description
Windows	Multiple windows allow different information to be displayed simultaneously on the user's screen.
Icons	Icons different types of information. On some systems, icons represent files; on others, icons represent processes.
Menus	Commands are selected from a menu rather than typed in a command language.
Pointing	A pointing device such as a mouse is used for selecting choices from a menu or indicating items of interest in a window.
Graphics	Graphical elements can be mixed with text on the same display.

GUI Advantages

- They are easy to learn and use.

Users without experience can learn to use the system quickly.

- The user may switch quickly from one task to another and can interact with several different applications.

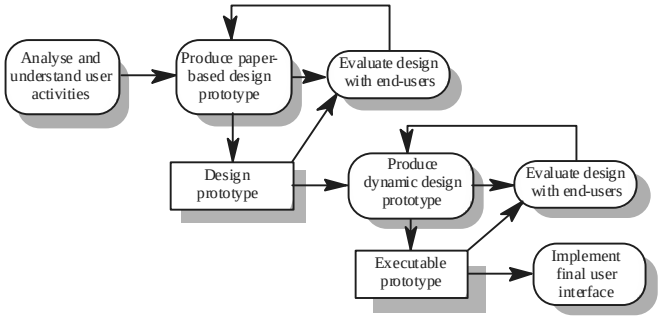
Information remains visible in its own window when attention is switched.

- Fast, full-screen interaction is possible with immediate access to anywhere on the screen

User-centred Design

- The aim of this chapter is to sensitise software engineers to key issues underlying the design rather than the implementation of user interfaces
- User-centred design is an approach to UI design where the needs of the user are paramount and where the user is involved in the design process
- UI design always involves the development of prototype interfaces

User Interface Design Process



UI Design Principles

- UI design must take account of the needs, experience and capabilities of the system users
- Designers should be aware of people's physical and mental limitations (e.g. limited short-term memory) and should recognise that people make mistakes
- UI design principles underlie interface designs although not all principles are applicable to all designs

Design Principles

- User familiarity

The interface should be based on user-oriented terms and concepts rather than computer concepts. For example, an office system should use concepts such as letters, documents, folders etc. rather than directories, file identifiers, etc.

- Consistency

The system should display an appropriate level of consistency. Commands and menus should have the same

- Minimal surprise

If a command operates in a known way, the user should be able to predict the operation of comparable commands

- Recoverability

The system should provide some resilience to user errors and allow the user to recover from errors. This might include an undo facility, confirmation of destructive actions, 'soft' deletes, etc.

- User guidance

Some user guidance such as help systems, on-line manuals, etc. should be supplied

- User diversity

Interaction facilities for different types of user should be supported. For example, some users have seeing difficulties and so larger text should be available

Format, command punctuation should be similar, etc.

User-system Interaction

- Two problems must be addressed in interactive systems design

How should information from the user be provided to the computer system?

How should information from the computer system be presented to the user?

- User interaction and information presentation may be integrated through a coherent framework such as a user interface metaphor

Interaction Styles

- Direct manipulation
- Menu selection
- Form fill-in
- Command language
- Natural language

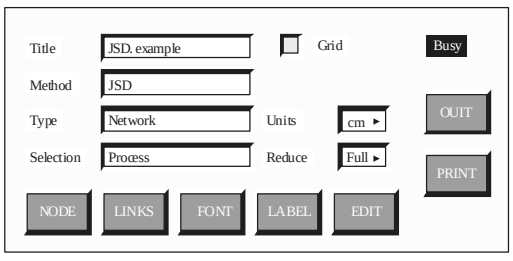
Direct Manipulation Advantages

- Users feel in control of the computer and are less likely to be intimidated by it
- User learning time is relatively short
- Users get immediate feedback on their actions so mistakes can be quickly detected and corrected

Direct Manipulation Problems

- The derivation of an appropriate information space model can be very difficult
- Given that users have a large information space, what facilities for navigating around that space should be provided?
- Direct manipulation interfaces can be complex to program and make heavy demands on the computer system

Control Panel Interface



Menu Systems

- Users make a selection from a list of possibilities presented to them by the system
- The selection may be made by pointing and clicking with a mouse, using cursor keys or by typing the name of the selection
- May make use of simple-to-use terminals such as touch screens

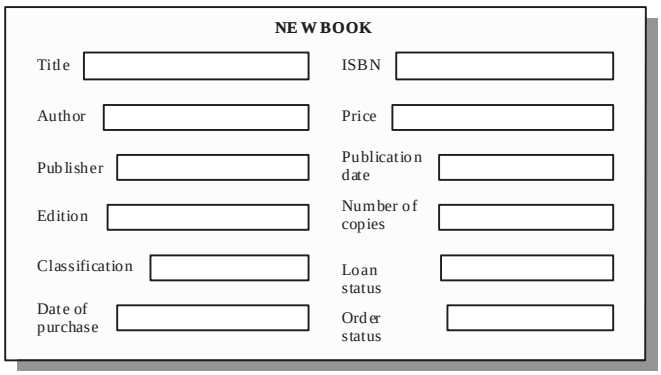
Advantages of Menu Systems

- Users need not remember command names as they are always presented with a list of valid commands
- Typing effort is minimal
- User errors are trapped by the interface
- Context-dependent help can be provided. The user's context is indicated by the current menu selection

Problems With Menu Systems

- Actions which involve logical conjunction (and) or disjunction (or) are awkward to represent
- Menu systems are best suited to presenting a small number of choices. If there are many choices, some menu structuring facility must be used
- Experienced users find menus slower than command language

Form-based Interface



Command Interfaces

- User types commands to give instructions to the system e.g. UNIX
- May be implemented using cheap terminals.
- Easy to process using compiler techniques
- Commands of arbitrary complexity can be created by command combination
- Concise interfaces requiring minimal typing can be created

Problems With Command Interfaces

- Users have to learn and remember a command language. Command interfaces are therefore unsuitable for occasional users
- Users make errors in command. An error detection and recovery system is required

- System interaction is through a keyboard so typing ability is required

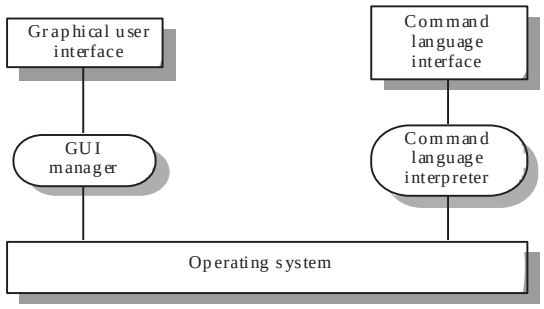
Command Languages

- Often preferred by experienced users because they allow for faster interaction with the system
- Not suitable for casual or inexperienced users
- May be provided as an alternative to menu commands (keyboard shortcuts). In some cases, a command language interface and a menu-based interface are supported at the same time

Natural Language Interfaces

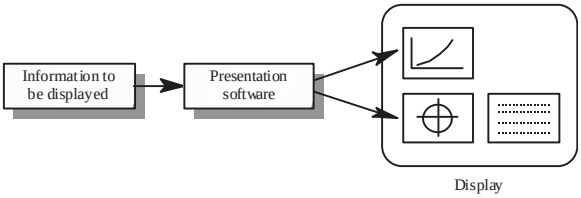
- The user types a command in a natural language. Generally, the vocabulary is limited and these systems are confined to specific application domains (e.g. timetable enquiries)
- NL processing technology is now good enough to make these interfaces effective for casual users but experienced users find that they require too much typing

Multiple User Interfaces

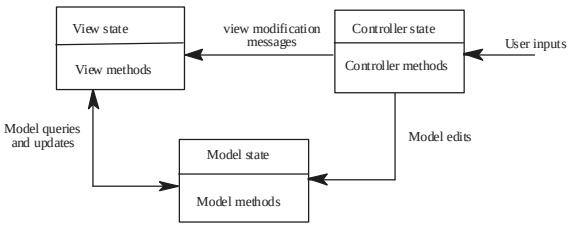


Information Presentation

- Information presentation is concerned with presenting system information to system users
- The information may be presented directly (e.g. text in a word processor) or may be transformed in some way for presentation (e.g. in some graphical form)
- The Model-View-Controller approach is a way of supporting multiple presentations of data



Model-view-controller



Information Presentation

- Static information

Initialised at the beginning of a session. It does not change during the session

May be either numeric or textual

- Dynamic information

Changes during a session and the changes must be communicated to the system user

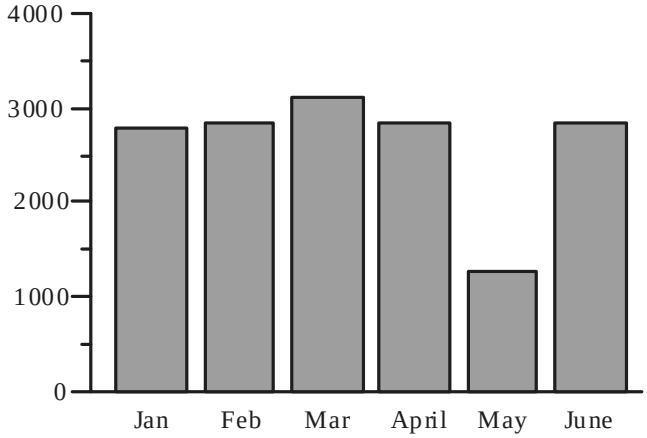
May be either numeric or textual

Information Display Factors

- Is the user interested in precise information or data relationships?
- How quickly do information values change? Must the change be indicated immediately?
- Must the user take some action in response to a change?
- Is there a direct manipulation interface?
- Is the information textual or numeric? Are relative values important?

Alternative Information Presentations

Jan	Feb	Mar	April	May	June
2842	2851	3164	2789	1273	2835



Analogue Vs. Digital Presentation

- Digital presentation

Compact - takes up little screen space

Precise values can be communicated

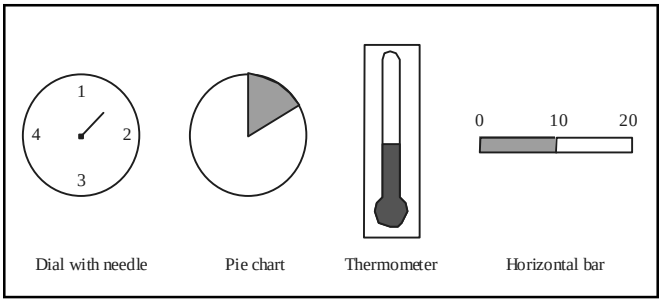
- Analogue presentation

Easier to get an 'at a glance' impression of a value

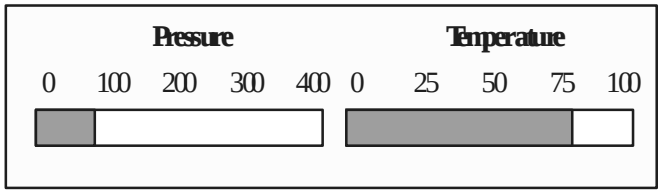
Possible to show relative values

Easier to see exceptional data values

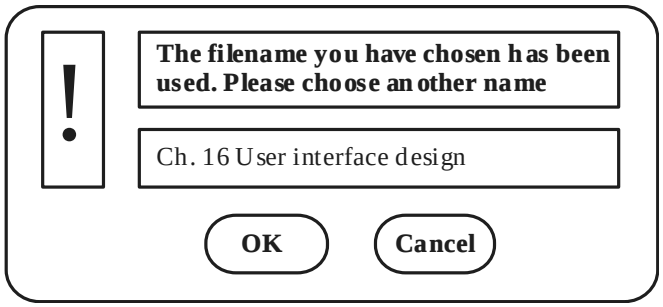
Dynamic Information Display



Displaying Relative Values



Textual Highlighting



Data Visualisation

- Concerned with techniques for displaying large amounts of information
- Visualisation can reveal relationships between entities and trends in the data
- Possible data visualisations are:

Weather information collected from a number of sources

The state of a telephone network as a linked set of nodes

Chemical plant visualised by showing pressures and temperatures in a linked set of tanks and pipes

A model of a molecule displayed in 3 dimensions

Web pages displayed as a hyperbolic tree

Colour Displays

- Colour adds an extra dimension to an interface and can help the user understand complex information structures
- Can be used to highlight exceptional events
- Common mistakes in the use of colour in interface design include:

The use of colour to communicate meaning

Over-use of colour in the display

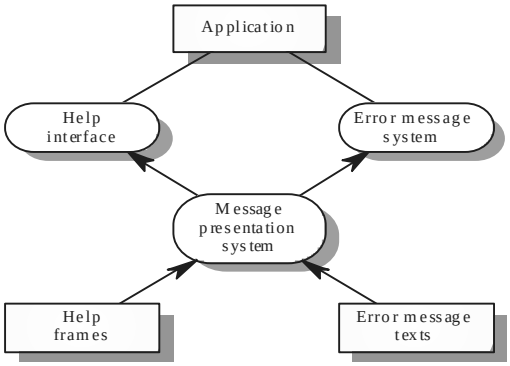
Colour Use Guidelines

- Don't use too many colours
- Use colour coding to support use tasks
- Allow users to control colour coding
- Design for monochrome then add colour
- Use colour coding consistently
- Avoid colour pairings, which clash
- Use colour change to show status change
- Be aware that colour displays are usually lower resolution

User Support

- User guidance covers all system facilities to support users including on-line help, error messages, manuals etc.
- The user guidance system should be integrated with the user interface to help users when they need information about the system or when they make some kind of error
- The help and message system should, if possible, be integrated

Help and Message System



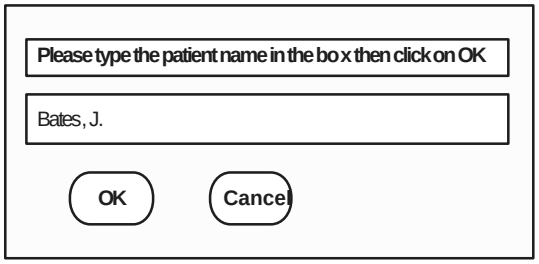
Error Messages

- Error message design is critically important. Poor error messages can mean that a user rejects rather than accepts a system
- Messages should be polite, concise, consistent and constructive
- The background and experience of users should be the determining factor in message design

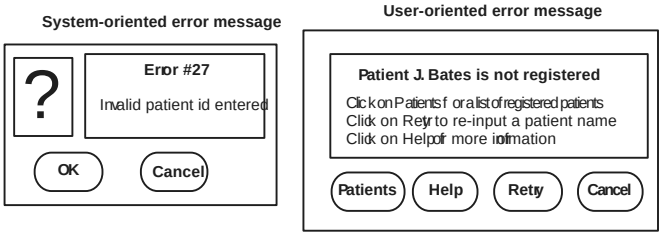
Design Factors in Message Wording

Context	The user guidance system should be aware of what the user is doing and should adjust the output message to the current context.
Experience	As users become familiar with a system they become irritated by long, 'meaningful' messages. However, beginners find it difficult to understand short terse statements of the problem. The user guidance system should provide both types of message and allow the user to control message conciseness.
Skill level	Messages should be tailored to the user's skills as well as their experience. Messages for the different classes of user may be expressed in different ways depending on the terminology which is familiar to the reader.
Style	Messages should be positive rather than negative. They should use the active rather than the passive mode of address. They should never be insulting or try to be funny.
Culture	Wherever possible, the designer of messages should be familiar with the culture of the country where the system is sold. There are distinct cultural differences between Europe, Asia and America. A suitable message for one culture might be unacceptable in another.

Nurse Input of a Patient's Name



System and User-oriented Error Messages



Help System Design

Help? means 'help I want information"

Help! means "HELP. I'm in trouble"

- Both of these requirements have to be taken into account in help system design
- Different facilities in the help system may be required

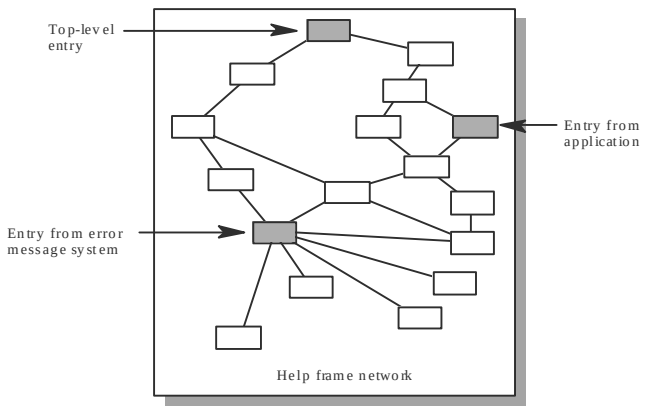
Help Information

- Should not simply be an on-line manual
- Screens or windows don't map well onto paper pages.
- The dynamic characteristics of the display can improve information presentation.
- People are not so good at reading screen as they are text.

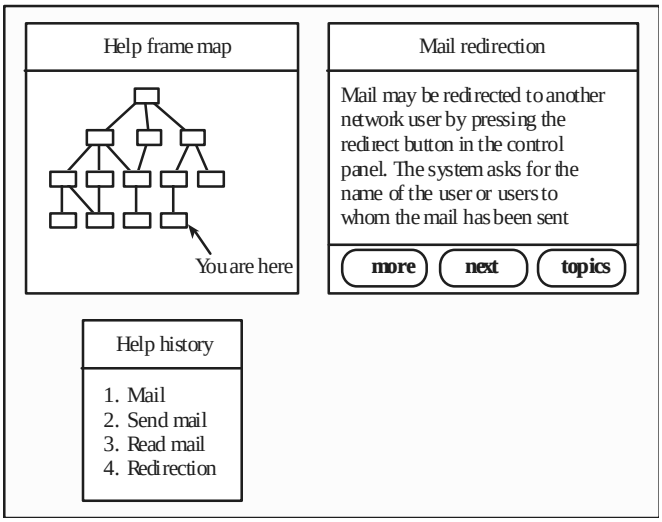
Help System Use

- Multiple entry points should be provided so that the user can get into the help system from different places.
- Some indication of where the user is positioned in the help system is valuable.
- Facilities should be provided to allow the user to navigate and traverse the help system.

Entry Points to a Help System



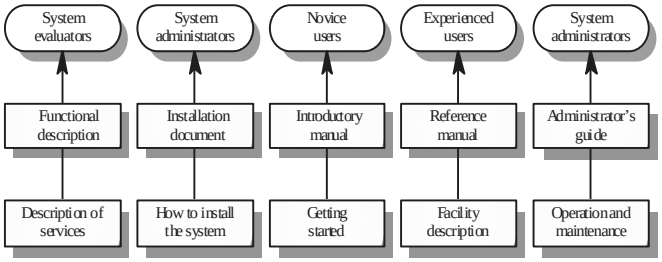
Help System Windows


Help frame map
You are here
Mail redirection
Mail may be redirected to another network user by pressing the redirect button in the control panel. The system asks for the name of the user or users to whom the mail has been sent
more
next
topics
Help history
1. Mail
2. Send mail
3. Read mail
4. Redirection

User Documentation

- As well as on-line information, paper documentation should be supplied with a system
- Documentation should be designed for a range of users from inexperienced to experienced
- As well as manuals, other easy-to-use documentation such as a quick reference card may be provided

User Document Types



Document Types

- Functional description

Brief description of what the system can do

- Introductory manual

Presents an informal introduction to the system

- System reference manual

Describes all system facilities in detail

- System installation manual

Describes how to install the system

- System administrator's manual

Describes how to manage the system when it is in use

User Interface Evaluation

- Some evaluation of a user interface design should be carried out to assess its suitability

- Full-scale evaluation is very expensive and impractical for most systems
- Ideally, an interface should be evaluated against a usability specification. However, it is rare for such specifications to be produced

Usability Attributes

Attribute	Description
Learnability	How long does it take a new user to become productive with the system?
Speed of operation	How well does the system response match the user's work practice?
Robustness	How tolerant is the system of user error?
Recoverability	How good is the system at recovering from user errors?
Adaptability	How closely is the system tied to a single model of work?

Simple Evaluation Techniques

- Questionnaires for user feedback
- Video recording of system use and subsequent tape evaluation.
- Instrumentation of code to collect information about facility use and user errors.
- The provision of a grip button for on-line user feedback.

Key Points

- Interface design should be user-centred. An interface should be logical and consistent and help users recover from errors
- Interaction styles include direct manipulation; menu systems form fill-in, command languages and natural language
- Graphical displays should be used to present trends and approximate values. Digital displays when precision is required
- Colour should be used sparingly and consistently
- Systems should provide on-line help. This should include "help, I'm in trouble" and "help, I want information"
- Error messages should be positive rather than negative.
- A range of different types of user documents should be provided
- Ideally, a user interface should be evaluated against a usability specification

Activity

Suggest situations where it is unwise or impossible to provide a consistent user interface.

Activity

What factors have to be taken into account when designing menu based interface for 'walkup' systems such as bank ATM machines? Write a critical commentary on the interface of an ATM that you use.

Activity

Suggest ways in which the user interface to an e- commerce system such as an online bookstore or music retailer might be adapted for users who are physically challenged with some form of casual impairment or problems with muscular control.

Activity

What are the guidelines which should be followed when using color in a user interface? Suggest how color might be used more effectively in the interface of an application system that you use.

Activity

Discuss the advantages of graphical information display and suggest four applications where it would be more appropriate to use graphical rather than digital displays of numeric information.

Activity

Write a short set of guidelines for designers of user guidance systems.

Activity 7: Design a questionnaire to gather information about the user interface f some tool (such as a word processor) with which you are familiar. If possible, distribute this questionnaire to a number of users and try to evaluate the results. What do these tell you about the user interface design?

Activity 8: What ethical issues might user interface designers face when trying to reconcile the needs of end-users of a system with the needs of the organization which is paying for the system to be developed?

Notes:

LESSON 26:
VERIFICATION AND VALIDATION

Objectives

- To introduce software verification and validation and to discuss the distinction between them.
- To describe the program inspection / review process and its role in V & V.
- To describe the Clean room software development process.

Topics Covered

- Software inspections / reviews
- Cleanroom software development

Verification Vs. Validation

- Verification:

"Are we building the product right?"

The software should conform to its specification.

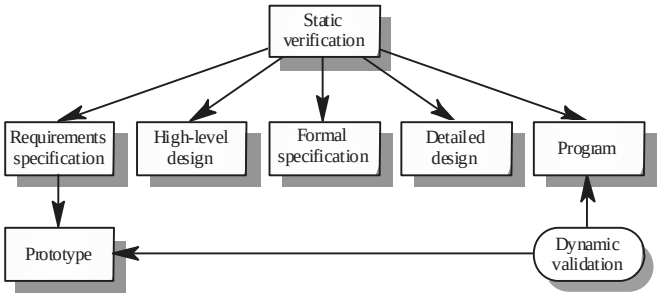
- Validation:

"Are we building the right product?"

The software should do what the user really needs / wants.

Static and Dynamic V&V

- Software inspections / reviews: analyse static system representations such as requirements, design, source code, etc. (static V & V)
- Software testing: executing an implementation of the software to examine outputs and operational behaviour (dynamic V & V)



Program Testing

- Defect testing: Tests designed to discover system defects. Sometimes referred to as coverage testing. (Covered after "Proofs of Correctness".)
- Statistical testing: Tests designed to assess system reliability and performance under operational conditions. Makes use of an operational profile.

V&V Goals

- Verification and validation should establish confidence that the software is "fit for purpose".
- This does NOT usually mean that the software must be completely free of defects.
- The level of confidence required depends on at least three factors…

Factors Affecting Level of Confidence Required

1. Software function / purpose: Safety-critical systems require a much higher level of confidence than demonstration-of-concept prototypes.
2. User expectations: Users may tolerate shortcomings when the benefits of use are high.
3. Marketing environment: Getting a product to market early may be more important than finding additional defects.

V&V Versus Debugging

- V&V and debugging are distinct processes.

V&V is concerned with establishing the existence of defects in a program.

Debugging is concerned with locating and " repairing these defects.

- Defect locating is analogous to detective work or medical diagnosis.

Software Inspections / Reviews

- Involve people examining a system representation (requirements, design, source code, etc.) with the aim of discovering anomalies and defects.
- They do not require execution so may be used before system implementation.
- Can be more effective than testing after system implementation. (As demonstrated in many studies.)

Why Code Inspections can be so Effective

- Many different defects may be discovered in a single inspection. (In testing, one defect may mask others so several executions may be required.)
- They reuse domain and programming language knowledge. (Reviewers are likely to have seen the types of error that commonly occur.)

Inspections and Testing are Complementary

- Inspections can be used early with non-executable entities and with source code at the module and component levels.
- Testing can validate dynamic behaviour and is the only effective technique at the sub-system and system code levels.
- Inspections cannot directly check non-functional requirements such as performance, usability, etc.

Program Inspections / Reviews

- Formalised approaches to document walk throughs or desk checking.
- Intended exclusively for defect DETECTION (not correction).

- Defects may be logical errors, anomalies in the code that might indicate an erroneous condition, or non-compliance with standards.

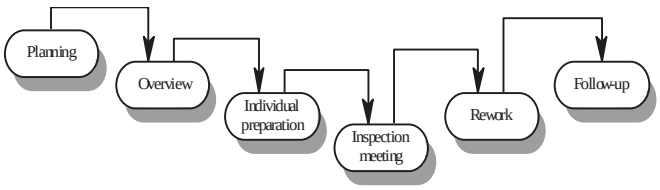
Inspection Pre-conditions ("Entry Criteria")

- A precise specification must be available.
- Team members must be familiar with the organization standards.
- Syntactically correct code must be available (for code inspections).

Inspection Pre-conditions

- An error checklist should be prepared.
- Management must accept the fact that inspection will increase costs early in the software process. (payoff comes later)
- Management must not use inspections results for staff appraisals. (Don't kill the goose that lays the golden eggs.)

The Inspection Process



Inspection Procedure

- System overview presented to inspection team.
- Code and associated documents are distributed to inspection team in advance.
- Inspection takes place and discovered errors are noted.
- Modifications are made to repair discovered errors (by owner).
- Re-inspection may or may not be required.

Inspection Teams

- Typically made up of 4-7 members.
- Author (owner) of the element being inspected.
- Inspectors who find errors, omissions and inconsistencies.
- Reader who steps through the element being reviewed with the team.
- Moderator who chairs the meeting and notes discovered errors.
- Other roles are Scribe and Chief moderator

Code Inspection Checklists

- Checklist of common errors should be used to drive individual preparation.
- Error checklist for is programming language dependent.
- The "weaker" the type checking (by the compiler), the larger the checklist.
- Examples: initialisation, constant naming, loop termination, array bounds, etc.

Inspection Checks

Fault class	Inspection check
Data faults	Are all program variables initialised before their values are used? Have all constants been named? Should the lower bound of arrays be 0, 1, or something else? Should the upper bound of arrays be equal to the size of the array or Size -1? If character strings are used, is a delimiter explicitly assigned?
Control faults	For each conditional statement, is the condition correct? Is each loop certain to terminate? Are compound statements correctly bracketed? In case statements, are all possible cases accounted for?
Input/output faults	Are all input variables used? Are all output variables assigned a value before they are output?
Interface faults	Do all function and procedure calls have the correct number of parameters? Do formal and actual parameter types match? Are the parameters in the right order? If components access shared memory, do they have the same model of the shared memory structure?
Storage management faults	If a linked structure is modified, have all links been correctly reassigned? If dynamic storage is used, has space been allocated correctly? Is space explicitly de-allocated after it is no longer required?
Exception management faults	Have all possible error conditions been taken into account?

Approximate Inspection Rate

- 500 statements/hour during overview.
- 125 source statement/hour during individual preparation.
- 90-125 statements/hour during inspection meeting.
- Inspection is therefore an expensive process.
- Inspecting 500 lines costs about 40 person/ hours (assuming 4 participants).

Cleanroom Software Development

- The name is derived from the 'Cleanroom' process in semiconductor fabrication.

The Philosophy is Defect Avoidance Rather Than Defect Removal.

- A software development process based on:

Incremental development (if appropriate)

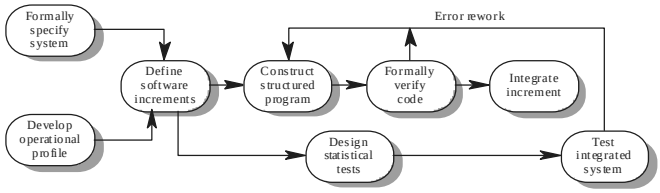
Formal specification

Static verification using correctness arguments

Statistical testing to certify program reliability

NO defect testing!

The Cleanroom Process



Cleanroom Process Teams

- Specification team: responsible for developing and maintaining the system specification
- Development team: responsible for developing and verifying the software. The software is NOT executed or even compiled during this process.
- Certification team: responsible for developing a set of statistical tests to measure reliability after development.

Clean Room Process Evaluation

- Results in IBM and elsewhere have been very impressive with very few discovered faults in delivered systems.
- Independent assessment shows that the process is no more expensive than other approaches.
- Not clear how this approach can be transferred to an environment with less skilled engineers.

Key Points

- Verification and validation are not the same. Verification shows conformance with a specification; validation shows conformance with customer's needs/desires.
- Static verification techniques involve examination and analysis of software elements for error detection.
- Program inspections are very effective in discovering errors.
- The Clean room development process depends on formal specification, static verification, and statistical testing.

Activity

Discuss the differences between verification and validation and explain why validations particularly difficult process.

Activity

Explain why it is not necessary for a program to be completely free of defects before it is delivered to its customers. To what extent can testing be used to validate that the program is fit for its purpose?

Activity

Explain why program inspections are an effective technique for discovering errors in a program. What types of error are unlikely to be discovered through inspections?

Activity

Explain why an organization with a competitive, elitist culture would probably find it difficult to introduce program inspections as a V& V technique.

Activity

Using your knowledge of Java, C++, C or some other programming language, derive a checklist of common errors (not syntax errors) which could not be detected by a complier but which might be detected in a program inspection.

Activity

Read the published papers on clean room development and write a management report highlighting the advantages, costs and risks of adopting this approach to software development.

Activity

A manager decides to use the reports of program inspections as an input to the stag appraisal process. These reports show who made and who discovered program errors. Is this ethical managerial behaviour? Would it be ethical if the staff were informed in advance that this would happen? What difference might it make to the inspection process?

Activity

One approach which is commonly adapted to system testing is to test the system until the testing budget is exhausted and then deliver the system to customers. Discuss the ethics of this approach.

LESSON 27 AND 28: SOFTWARE TESTING

Objectives

- To understand testing techniques that are geared to discover program faults
- To introduce guidelines for interface testing
- To understand specific approaches to object-oriented testing
- To understand the principles of CASE tool support for testing

Topics Covered

- Defect testing
- Integration testing
- Object-oriented testing
- Testing workbenches

The Testing Process

- Component testing

Testing of individual program components

Usually the responsibility of the component developer (except sometimes for critical systems)

Tests are derived from the developer's experience

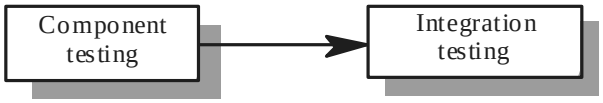
- Integration testing

Testing of groups of components integrated to create a system or sub-system

The responsibility of an independent testing team

Tests are based on a system specification

Testing Phases



Defect Testing

- Testing programs to establish the presence of system defects
- The goal of defect testing is to discover defects in programs
- A successful defect test is a test, which causes a program to behave in an anomalous way
- Tests show the presence not the absence of defects

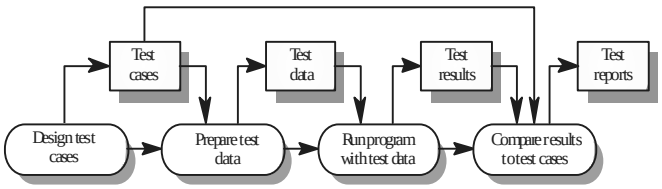
Testing Priorities

- Only exhaustive testing can show a program is free from defects. However, exhaustive testing is impossible
- Tests should exercise a system's capabilities rather than its components
- Testing old capabilities is more important than testing new capabilities
- Testing typical situations is more important than boundary value cases

Test Data and Test Cases

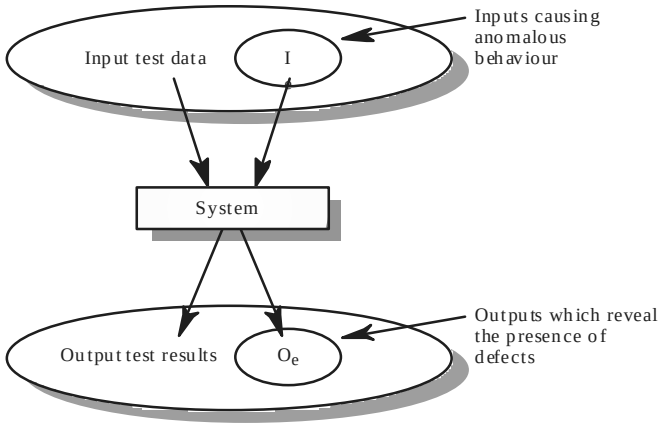
- Test data Inputs, which have been devised to test the system
- Test cases Inputs to test the system and the predicted outputs from these inputs if the system operates according to its specification

The Defect Testing Process



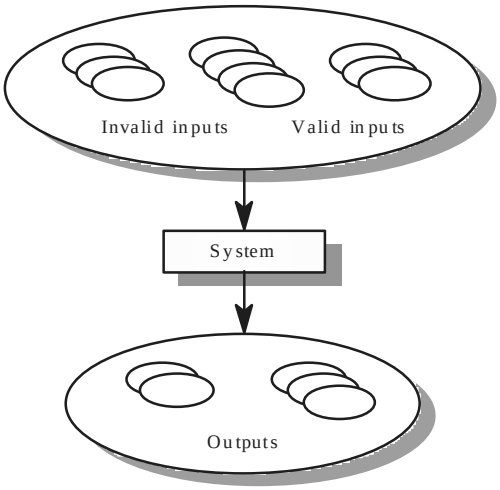
Black-box Testing

- An approach to testing where the program is considered as a 'black-box'
- The program test cases are based on the system specification
- Test planning can begin early in the software process



Equivalence Partitioning

- Input data and output results often fall into different classes where all members of a class are related
- Each of these classes is an equivalence partition where the program behaves in an equivalent way for each class member
- Test cases should be chosen from each partition



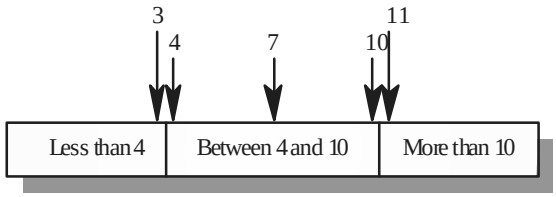
- Partition system inputs and outputs into 'equivalence sets'

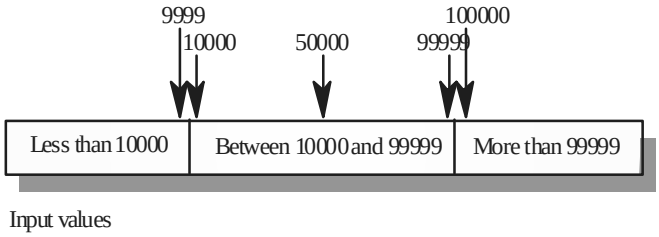
If input is a 5-digit integer between 10,000 and 99,999, equivalence partitions are <10,000, 10,000-99, 999 and > 10, 000

Choose test cases at the boundary of these sets

00000, 09999, 10000, 99999, 10001

Equivalence Partitions





Search Routine Specification

Procedure Search (Key: ELEM; T: ELEM_ARRAY;
Found: in out BOOLEAN; L: in out ELEM_INDEX) ;

Pre-condition : the array has at least one element
T'FIRST <= T'LAST

Post-condition : the element is found and is referenced by L
(Found and T (L) = Key)

or

: the element is not in the array
(Not Found and not (exists i, T'FIRST >= i <= T'LAST, T (i) = Key))

Search Routine : Input Partitions

- Inputs, which conform to the pre-conditions
- Inputs where a pre-condition does not hold
- Inputs where the key element is a member of the array
- Inputs where the key element is not a member of the array

Testing Guidelines (Sequences)

- Test software with sequences, which have only a single value
- Use sequences of different sizes in different tests
- Derive tests so that the first, middle and last elements of the sequence are accessed
- Test with sequences of zero length

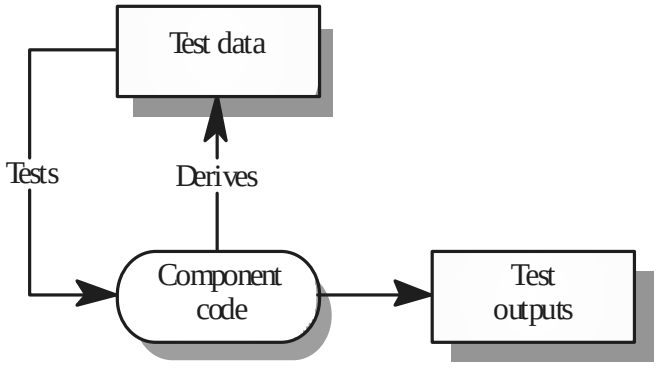
Search Routine - Input Partitions

Array	**Element**
Single value	In sequence
Single value	Not in sequence
More than 1 value	First element in sequence
More than 1 value	Last element in sequence
More than 1 value	Middle element in sequence
More than 1 value	Not in sequence

Input sequence (T)	**Key** (Key)	**Output** (Found, L)
17	17	true, 1
17	0	false, ??
17, 29, 21, 23	17	true, 1
41, 18, 9, 31, 30, 16, 45	45	true, 7
17, 18, 21, 23, 29, 41, 38	23	true, 4
21, 23, 29, 33, 38	25	false, ??

White-box Testing

- Sometimes called Structural testing
- Derivation of test cases according to program structure. Knowledge of the program is used to identify additional test cases
- Objective is to exercise all program statements (not all path combinations)

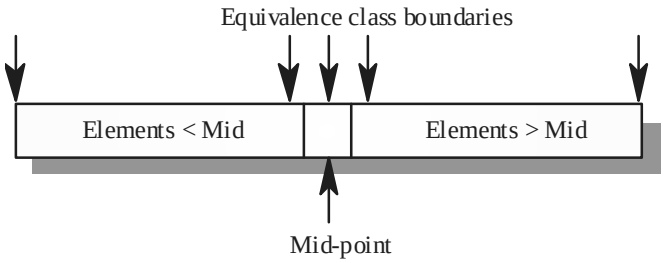


Binary Search (Java)

```
class BinSearch {

// This is an encapsulation of a binary search function that takes an array of
// ordered objects and a key and returns an object with 2 attributes namely
// index - the value of the array index
// found - a boolean indicating whether or not the key is in the array
// An object is returned because it is not possible in Java to pass basic types by
// reference to a function and so return two values
// the key is -1 if the element is not found

        public static void search ( int key, int [] elemArray, Result r )
        {
                int bottom = 0 ;
                int top = elemArray.length - 1 ;
                int mid ;
                r.found = false ; r.index = -1 ;
                while ( bottom <= top )
                {
                        mid = (top + bottom) / 2 ;
                        if (elemArray [mid] == key)
                        {
                                r.index = mid ;
                                r.found = true ;
                                return ;
                        } // if part
                        else
                        {
                                if (elemArray [mid] < key)
                                        bottom = mid + 1 ;
                                else
                                        top = mid - 1 ;
                        }
                } //while loop
        } // search
} //BinSearch
```

Binary Search - Equiv. Partitions

- Pre-conditions satisfied, key element in array
- Pre-conditions satisfied, key element not in array
- Pre-conditions unsatisfied, key element in array
- Pre-conditions unsatisfied, key element not in array
- Input array has a single value
- Input array has an even number of values
- Input array has an odd number of values



Binary Search - Test Cases

Input array (T)	**Key** (Key)	**Output** (Found, L)
17	17	true, 1
17	0	false, ??
17, 21, 23, 29	17	true, 1
9, 16, 18, 30, 31, 41, 45	45	true, 7
17, 18, 21, 23, 29, 38, 41	23	true, 4
17, 18, 21, 23, 29, 33, 38	21	true, 3
12, 18, 21, 23, 32	23	true, 4
21, 23, 29, 33, 38	25	false, ??

Path Testing

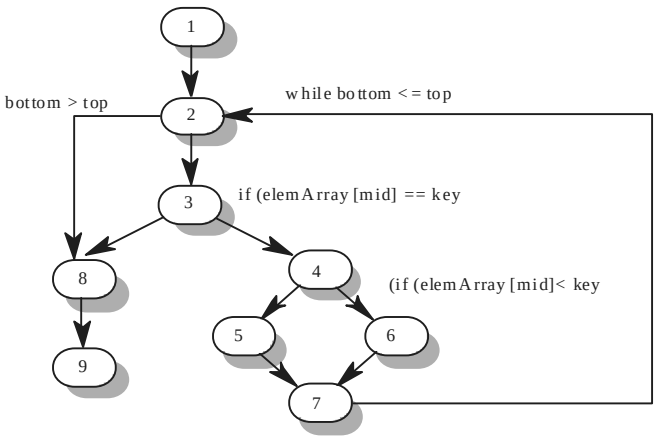
- The objective of path testing is to ensure that the set of test cases is such that each path through the program is executed at least once
- The starting point for path testing is a program flow graph that shows nodes representing program decisions and arcs representing the flow of control
- Statements with conditions are therefore nodes in the flow graph

Program Flow Graphs

- Describes the program control flow. Each branch is shown as a separate path and loops are shown by arrows looping back to the loop condition node
- Used as a basis for computing the cyclomatic complexity
- Cyclomatic complexity = Number of edges - Number of nodes +2

Cyclomatic Complexity

- The number of tests to test all control statements equals the cyclomatic complexity
- Cyclomatic complexity equals number of conditions in a program
- Useful if used with care. Does not imply adequacy of testing.
- Although all paths are executed, all combinations of paths are not executed



Binary search flow graph

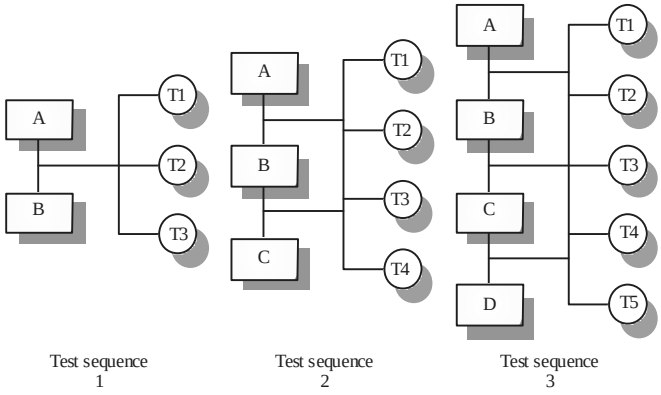
Independent Paths

- 1, 2, 3, 8, 9
- 1, 2, 3, 4, 6, 7, 2
- 1, 2, 3, 4, 5, 7, 2
- 1, 2, 3, 4, 6, 7, 2, 8, 9
- Test cases should be derived so that all of these paths are executed
- A dynamic program analyser may be used to check that paths have been executed

Integration Testing

- Tests complete systems or subsystems composed of integrated components
- Integration testing should be black-box testing with tests derived from the specification
- Main difficulty is localising errors
- Incremental integration testing reduces this problem

Incremental Integration Testing



Approaches to Integration Testing

- Top-down testing

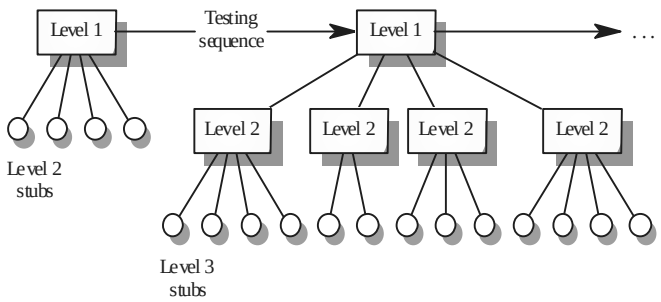
Start with high-level system and integrate from the top-down replacing individual components by stubs where appropriate

- Bottom-up testing

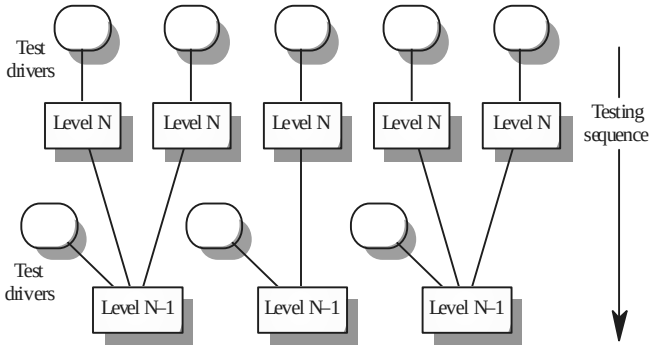
Integrate individual components in levels until the complete system is created

- In practice, most integration involves a combination of these strategies

Top-down Testing



Bottom-up Testing



Testing Approaches

- Architectural validation

Top-down integration testing is better at discovering errors in the system architecture

- System demonstration

Top-down integration testing allows a limited demonstration at an early stage in the development

- Test implementation

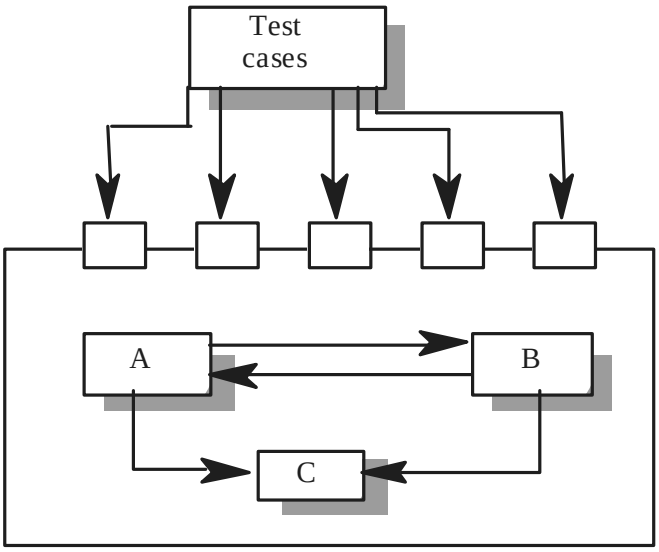
Often easier with bottom-up integration testing

- Test observation

Problems with both approaches. Extra code may be required to observe tests

Interface Testing

- Takes place when modules or sub-systems are integrated to create larger systems
- Objectives are to detect faults due to interface errors or invalid assumptions about interfaces
- Particularly important for object-oriented development as objects are defined by their interfaces



Interfaces Types

- Parameter interfaces

Data passed from one procedure to another

- Shared memory interfaces

Block of memory is shared between procedures

Procedural interfaces

Sub-system encapsulates a set of procedures to be called by other sub-systems

- Message passing interfaces

Sub-systems request services from other sub-systems

Interface Errors

- Interface misuse

A calling component calls another component and makes an error in its use of its interface e.g. parameters in the wrong order

- Interface misunderstanding

A calling component embeds assumptions about the behaviour of the called component, which are incorrect

- Timing errors

The called and the calling component operate at different speeds and out-of-date information is accessed

Interface Testing Guidelines

- Design tests so that parameters to a called procedure are at the extreme ends of their ranges
- Always test pointer parameters with null pointers
- Design tests, which cause the component to fail
- Use stress testing in message passing systems
- In shared memory systems, vary the order in which components are activated

Stress Testing

- Exercises the system beyond its maximum design load. Stressing the system often causes defects to come to light
- Stressing the system test failure behaviour.. Systems should not fail catastrophically. Stress testing checks for unacceptable loss of service or data
- Particularly relevant to distributed systems which can exhibit severe degradation as a network becomes overloaded

Object-oriented Testing

- The components to be tested are object classes that are instantiated as objects
- Larger grain than individual functions so approaches to white-box testing have to be extended
- No obvious 'top' to the system for top-down integration and testing

Testing Levels

- Testing operations associated with objects
- Testing object classes
- Testing clusters of cooperating objects
- Testing the complete OO system

Object Class Testing

- Complete test coverage of a class involves

Testing all operations associated with an object

Setting and interrogating all object attributes

Exercising the object in all possible states

- Inheritance makes it more difficult to design object class tests, as the information to be tested is not localised

Weather Station Object Interface

Weather Station
identifier
reportWeather() calibrate(instruments) test () startup(instruments) shutdown(instruments)

- Test cases are needed for all operations
- Use a state model to identify state transitions for testing
- Examples of testing sequences

Shutdown : Waiting : Shutdown

Waiting : Calibrating : Testing : Transmitting : Waiting

Waiting : Collecting : Waiting : Summarising : Transmitting : Waiting

Object Integration

- Levels of integration are less distinct in object-oriented systems
- Cluster testing is concerned with integrating and testing clusters of cooperating objects
- Identify clusters using knowledge of the operation of objects and the system features that are implemented by these clusters

Approaches to Cluster Testing

- Use-case or scenario testing

Testing is based on user interactions with the system

Has the advantage that it tests system features as experienced by users

- Thread testing

Tests the systems response to events as processing threads through the system

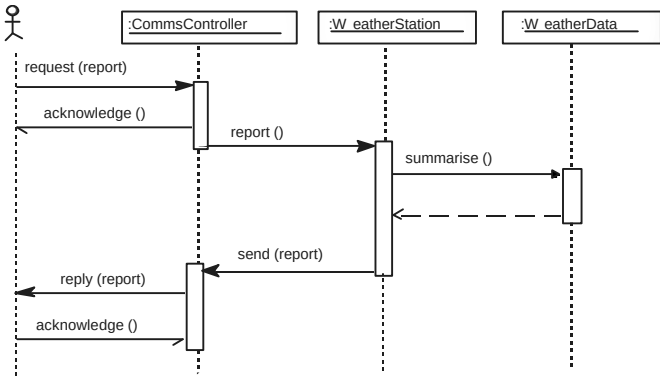
- Object interaction testing

Tests sequences of object interactions that stop when an object operation does not call on services from another object

Scenario-based Testing

- Identify scenarios from use-cases and supplement these with interaction diagrams that show the objects involved in the scenario
- Consider the scenario in the weather station system where a report is generated

Collect Weather Data



Weather Station Testing

- Thread of methods executed

CommsController: request - WeatherStation: report - WeatherData: summarise

- Inputs and outputs

Input of report request with associated acknowledge and a final output of a report

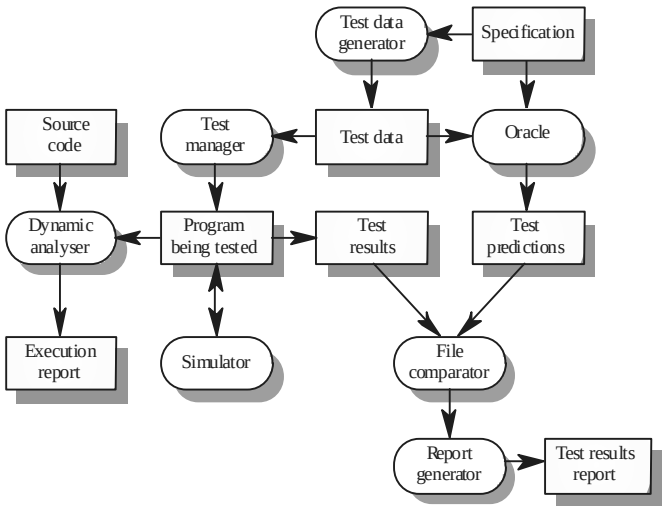
Can be tested by creating raw data and ensuring that it is summarised properly

Use the same raw data to test the Weather Data object

Testing Workbenches

- Testing is an expensive process phase. Testing workbenches provide a range of tools to reduce the time required and total testing costs
- Most testing workbenches are open systems because testing needs are organisation-specific
- Difficult to integrate with closed design and analysis workbenches

A Testing Workbench



Testing Workbench Adaptation

- Scripts may be developed for user interface simulators and patterns for test data generators
- Test outputs may have to be prepared manually for comparison
- Special-purpose file comparators may be developed

Key Points

- Test parts of a system which are commonly used rather than those which are rarely executed
- Equivalence partitions are sets of test cases where the program should behave in an equivalent way
- Black-box testing is based on the system specification
- Structural testing identifies test cases, which cause all paths through the program to be executed
- Test coverage measures ensure that all statements have been executed at least once.
- Interface defects arise because of specification misreading, misunderstanding, errors or invalid timing assumptions
- To test object classes, test all operations, attributes and states
- Integrate object-oriented systems around clusters of objects

Activity

Discuss the differences between black box and structural testing and suggest how they can be used together in the defect testing process.

Activity

What testing problems might arise in numerical routines designed to handle very large and very small numbers?

Activity

Derive a set of test for the following components:

- A sort routine, which sorts arrays of integers.
- A routine, which takes a line of text as input and counts the number of non-blank characters in that line.

Activity

Show, using a small example, why it is practically impossible to exhaustively test a program.

Activity

Explain why interface testing is necessary given that individual units have been extensively validated through unit testing and program inspections.

Activity

Explain why bottom-up and top-down testing may be inappropriate testing strategies for object oriented systems.

LESSON 29 AND 30: MANAGING PEOPLE

Managing People Working As Individuals And In Groups

Objectives

- To describe simple models of human cognition and their relevance for software managers
- To explain the key issues that determine the success or otherwise of team working
- To discuss the problems of selecting and retaining technical staff
- To introduce the people capability maturity model (P-CMM)

Topics Covered

- Limits to thinking
- Group working
- Choosing and keeping people
- The people capability maturity model

People in the Process

- People are an organisation's most important assets
- The tasks of a manager are essentially people oriented. Unless there is some understanding of people, management will be unsuccessful
- Software engineering is primarily a cognitive activity. Cognitive limitations effectively limit the software process

Management Activities

- Problem solving (using available people)
- Motivating (people who work on a project)
- Planning (what people are going to do)
- Estimating (how fast people will work)
- Controlling (people's activities)
- Organising (the way in which people work)

Limits to Thinking

- People don't all think the same way but everyone is subject to some basic constraints on their thinking due to

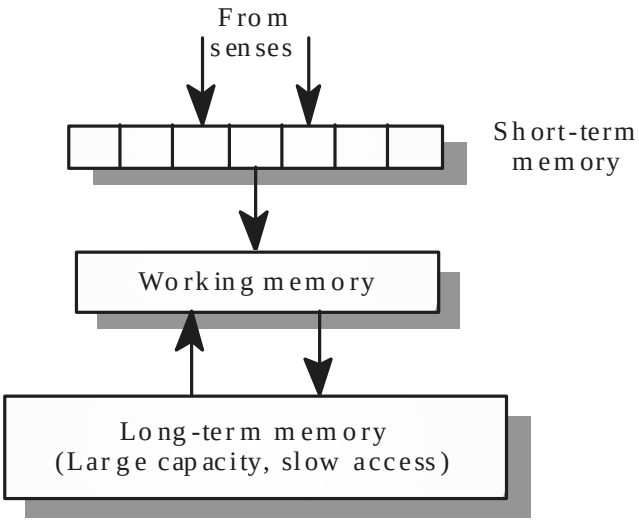
Memory organisation

Knowledge representation

Motivation influences

- If we understand these constraints, we can understand how they affect people participating in the software process

Memory Organisation



Short-term Memory

- Fast access, limited capacity
- 5-7 locations
- Holds 'chunks' of information where the size of a chunk may vary depending on its familiarity
- Fast decay time

Working Memory

- Larger capacity, longer access time
- Memory area used to integrate information from short-term memory and long-term memory.
- Relatively fast decay time.

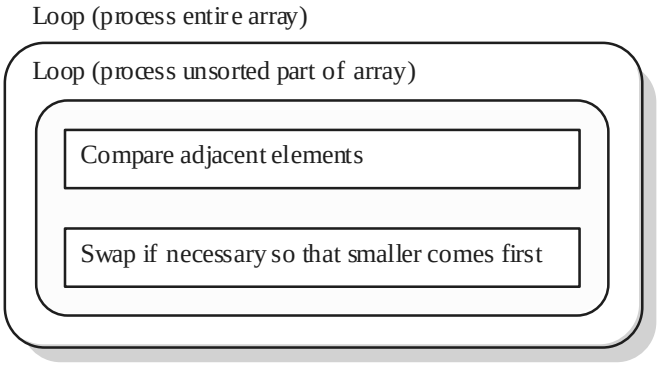
Long-term Memory

- Slow access, very large capacity
- Unreliable retrieval mechanism
- Slow but finite decay time - information needs reinforced
- Relatively high threshold - work has to be done to get information into long-term memory.

Information Transfer

- Problem solving usually requires transfer between short-term memory and working memory
- Information may be lost or corrupted during this transfer
- Information processing occurs in the transfer from short-term to long-term memory

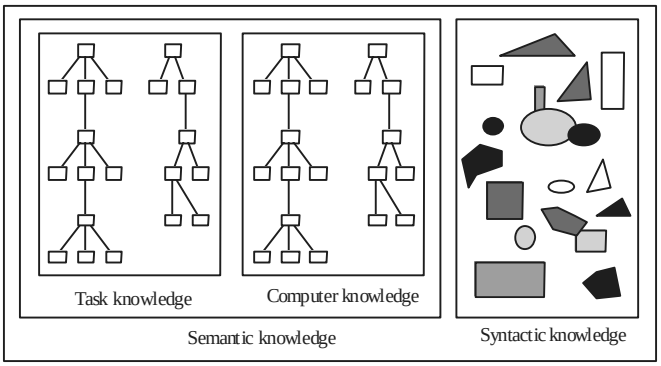
Cognitive Chunking


Loop (process entire array)
Loop (process unsorted part of array)
Compare adjacent elements
Swap if necessary so that smaller comes first

Knowledge Modelling

- Semantic knowledge: knowledge of concepts such as the operation of assignment, concept of parameter passing etc.
- Syntactic knowledge: knowledge of details of a representation e.g. an Ada while loop.
- Semantic knowledge seems to be stored in a structured, representation independent way.

Syntactic/Semantic Knowledge



Knowledge Acquisition

- Semantic knowledge through experience and active learning - the 'ah' factor
- Syntactic knowledge acquired by memorisation.
- New syntactic knowledge can interfere with existing syntactic knowledge.

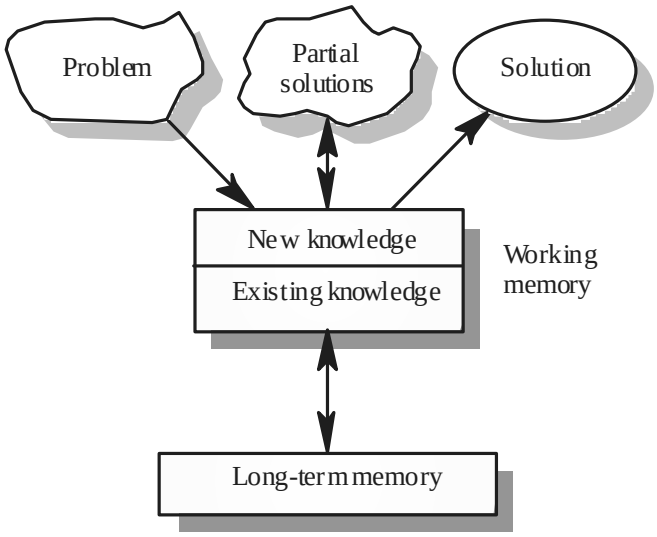
Problems arise for experienced programmers in mixing up syntax of different programming languages

Semantic Knowledge

- Computing concepts : notion of a writable store, iteration, concept of an object, etc.
- Task concepts : principally algorithmic - how to tackle a particular task
- Software development ability is the ability to integrate new knowledge with existing computer and task knowledge and hence derive creative problem solutions
- Thus, problem solving is language independent

Problem Solving

- Requires the integration of different types of knowledge (computer, task, domain, organisation)
- Development of a semantic model of the solution and testing of this model against the problem
- Representation of this model in an appropriate notation or programming language



Motivation

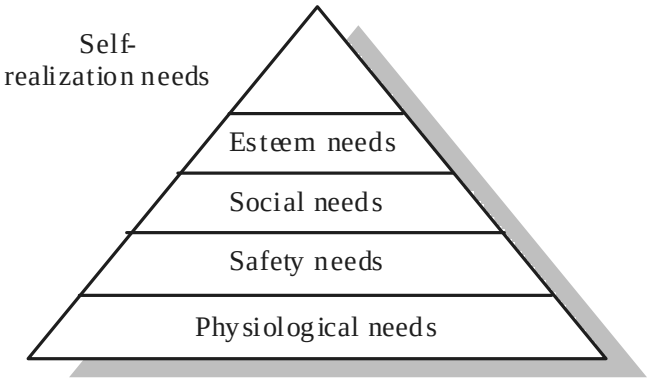
- An important role of a manager is to motivate the people working on a project
- Motivation is a complex issue but it appears that their are different types of motivation based on

Basic needs (e.g. food, sleep, etc.)

Personal needs (e.g. respect, self-esteem)

Social needs (e.g. to be accepted as part of a group)

Human Needs Hierarchy



Motivating People

- Motivations depend on satisfying needs
- It can be assumed that physiological and safety needs are satisfied

- Social, esteem and self-realization needs are most significant from a managerial viewpoint

Need Satisfaction

- Social

Provide communal facilities

Allow informal communications

- Esteem

Recognition of achievements

Appropriate rewards

- Self-realization

Training - people want to learn more

Responsibility

Personality Types

- The needs hierarchy is almost certainly an over-simplification
- Motivation should also take into account different personality types:

Task-oriented

Self-oriented

Interaction-oriented

- Task-oriented.

The motivation for doing the work is the work itself

- Self-oriented.

The work is a means to an end which is the achievement of individual goals - e.g. to get rich, to play tennis, to travel etc.

- Interaction-oriented

The principal motivation is the presence and actions of co-workers. People go to work because they like to go to work

Motivation Balance

- Individual motivations are made up of elements of each class
- Balance can change depending on personal circumstances and external events
- However, people are not just motivated by personal factors but also by being part of a group and culture.
- People go to work because they are motivated by the people that they work with

Group Working

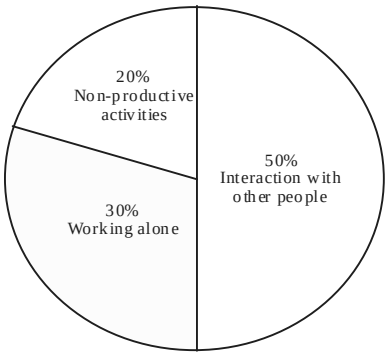
- Most software engineering is a group activity

The development schedule for most non-trivial software projects is such that they cannot be completed by one person working alone

- Group interaction is a key determinant of group performance
- Flexibility in group composition is limited

Managers must do the best they can with available people

Time Distribution



Group Composition

- Group composed of members who share the same motivation can be problematic

Task-oriented : everyone wants to do their own thing

Self-oriented : everyone wants to be the boss

Interaction-oriented : too much chatting, not enough work

- An effective group has a balance of all types
- Can be difficult to achieve because most engineers are task-oriented
- Need for all members to be involved in decisions, which affect the group

Group Leadership

- Leadership depends on respect not titular status
- There may be both a technical and an administrative leader
- Democratic leadership is more effective that autocratic leadership
- A career path based on technical competence should be supported

Group Cohesiveness

- In a cohesive group, members consider the group to be more important than any individual in it
- Advantages of a cohesive group are:

Group quality standards can be developed

Group members work closely together so inhibitions caused by ignorance are reduced

Team members learn from each other and get to know each other's work

Ego less programming where members strive to improve each other's programs can be practised

Developing Cohesiveness

- Cohesiveness is influenced by factors such as the organisational culture and the personalities in the group
- Cohesiveness can be encouraged through

Social events

Developing a group identity and territory

Explicit team-building activities

- Openness with information is a simple way of ensuring all group members feel part of the group

Group Loyalties

- Group members tend to be loyal to cohesive groups
- 'Groupthink' is preservation of group irrespective of technical or organizational considerations
- Management should act positively to avoid groupthink by forcing external involvement with each group

Group Communications

- Good communications are essential for effective group working
- Information must be exchanged on the status of work, design decisions and changes to previous decisions
- Good communications also strengthens group cohesion as it promotes understanding
- Status of group members

Higher status members tend to dominate conversations

- Personalities in groups

Too many people of the same personality type can be a problem

- Sexual composition of group

Mixed-sex groups tend to communicate better

- Communication channels

Communications channelled though a central coordinator tend to be ineffective

Group Organisation

- Software engineering group sizes should be relatively small (< 8 members)
- Break big projects down into multiple smaller projects
- Small teams may be organised in an informal, democratic way
- Chief programmer teams try to make the most effective use of skills and experience

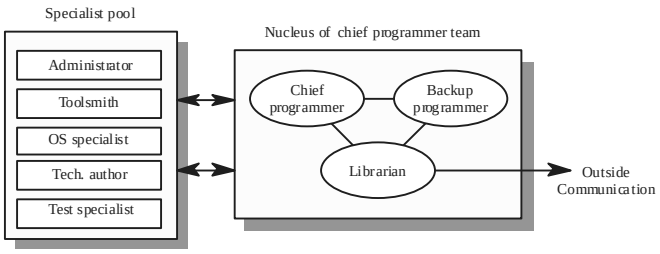
Democratic Team Organisation

- The group acts as a whole and comes to a consensus on decisions affecting the system
- The group leader serves as the external interface of the group but does not allocate specific work items
- Rather, work is discussed by the group as a whole and tasks are allocated according to ability and experience
- This approach is successful for groups where all members are experienced and competent

Extreme Programming Groups

- Extreme programming groups are variants of democratic organisation
- In extreme programming groups, some 'management' decisions are devolved to group members
- Programmers work in pairs and take a collective responsibility for code that is developed

Chief Programmer Teams



- Consist of a kernel of specialists helped by others added to the project as required
- The motivation behind their development is the wide difference in ability in different programmers
- Chief programmer teams provide a supporting environment for very able programmers to be responsible for most of the system development

Problems

- This chief programmer approach, in different forms, has undoubtedly been successful
- However, it suffers from a number of problems

Talented designers and programmers are hard to find. Without exception people in these roles, the approach will fail

Other group members may resent the chief programmer taking the credit for success so may deliberately undermine his/her role

High project risk as the project will fail if both the chief and deputy programmer are unavailable

Organisational structures and grades may be unable to accommodate this type of group

Choosing and Keeping People

- Choosing people to work on a project is a major managerial responsibility
- Appointment decisions are usually based on

information provided by the candidate (their resume or CV)

information gained at an interview

recommendations from other people who know the candidate

- Some companies use psychological or aptitude tests

There is no agreement on whether or not these tests are actually useful

Staff Selection Factors

Factor	Explanation
Application domain experience	For a project to develop a successful system, the developers must understand the application domain.
Platform experience	May be significant if low-level programming is involved. Otherwise, not usually a critical attribute.
Programming language experience	Normally only significant for short duration projects where there is insufficient time to learn a new language.
Educational background	May provide an indicator of the basic fundamentals which the candidate should know and of their ability to learn. This factor becomes increasingly irrelevant as engineers gain experience across a range of projects.
Communication ability	Very important because of the need forproject staff to communicate orally and in writing with other engineers, managers and customers.
Adaptability	Adaptability may be judged by looking at the different types of experience which candidates have had.This is an important attribute as it indicates an ability to learn.
Attitude	Project staff should have a positive attitude to their work andshould be willing to learn new skills. This is an important attribute but often very difficult to assess.
Personality	Again, an important attribute but difficult to assess. Candidates must be reasonably compatible with other team members. No particular type of personality is more or less suited to software engineering.

Working Environments

- Physical workplace provision has an important effect on individual productivity and satisfaction

Comfort

Privacy

Facilities

- Health and safety considerations must be taken into account

Lighting

Heating

Furniture

Environmental Factors

- Privacy : each engineer requires an area for uninterrupted work
- Outside awareness : people prefer to work in natural light
- Personalization : individuals adopt different working practices and like to organize their environment in different ways

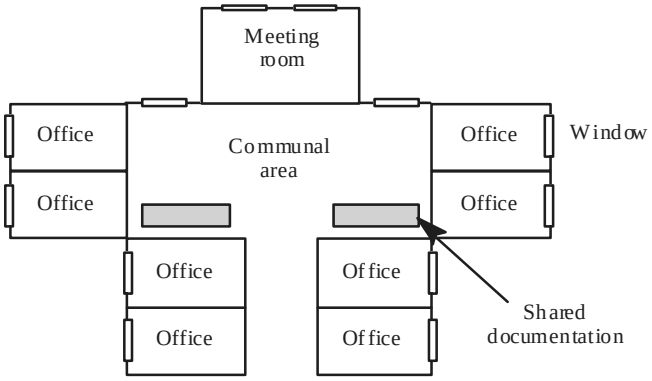
Workspace Organisation

- Workspaces should provide private spaces where people can work without interruption

Providing individual offices for staff has been shown to increase productivity

- However, teams working together also require spaces where formal and informal meetings can be held

Office Layout



The People Capability Maturity Model

- Intended as a framework for managing the development of people involved in software development
- Five stage model

Initial : Ad-hoc people management

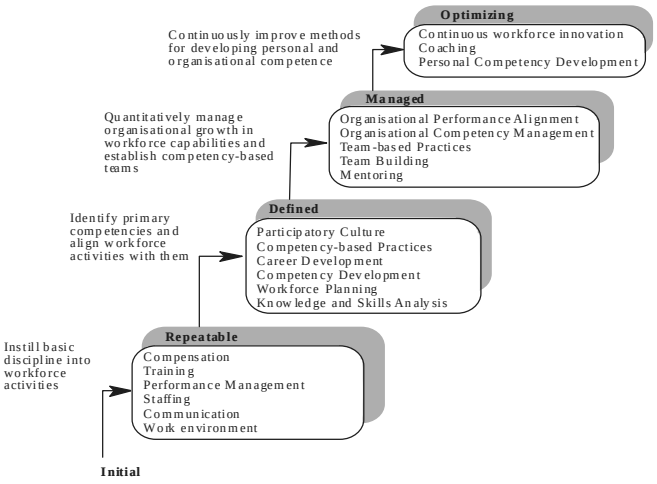
Repeatable : Policies developed for capability improvement

Defined : Standardised people management across the organisation

Managed : Quantitative goals for people management in place

Optimising : Continuous focus on improving individual competence and workforce motivation

The People Capability Maturity Model



P-CMM Objectives

- To improve organisational capability by improving workforce capability
- To ensure that software development capability is not reliant on a small number of individuals
- To align the motivation of individuals with that of the organisation
- To help retain people with critical knowledge and skills

Key Points

- Managers must have some understanding of human factors to avoid making unrealistic demands on people
- Problem solving involves integrating information from long-term memory with new information from short-term memory
- Staff selection factors include education, domain experience, adaptability and personality
- Software development groups should be small and cohesive
- Group communications are affected by status, group size, group organisation and the sexual composition of the group
- The working environment has a significant effect on productivity
- The People Capability Maturity Model is a framework for improving the capabilities of staff in an organisation

Activity

What is the difference between syntactic and semantic knowledge? Form your own experience; suggest a number of instances of each of these types of knowledge.

Activity

What factors should be taken into account when selecting staff to work on a software development project?

Activity

As a training manager, you are responsible for the initial programming language training of a new graduate intake to your company whose business is the development of defense aerospace systems. The principal programming language used is Ada, which was designed for defense systems programming. The trainees may be computer science graduates, engineers or physical scientists. Some but not all of the trainees have previous programming experience; none have previous experience in Ada. Explain how you would structure the programming t4aining for this group of graduates.

Activity

Explain why keeping all members of a group informed about progress and technical decisions in a project can improve group cohesiveness.

Activity

Explain what you understand by 'groupthink'. Describe the dangers of this phenomenon and explain how it might be avoided.

Activity

You are a programming manager who has been given the task of rescuing a project that is critical to the success of the company. Senior management have given you an open-ended budget and you may choose a project team of yup to five people form any other projects going on in the company. However, a rival company, working in the same area, is actively recruiting staff and several staff working for your company has left to join them.

Describe tow models of programming team organization that might be used in this situation and make a choice of one of these models. Give reasons for your choice and explain why you have rejected the alternative model.

Activity

Why are open plan and communal offices sometimes less suitable for software development than individual officers? Under what circumstances do you think that open-plan environments might be better?

Activity

Why is the P - CMM an effective framework for improving the management of people in an organization? Suggest how it may have to be modified if it is to be used in small companies.

Notes:

Activity

Should managers become friendly and mix socially with more junior members of their group?

Activity

Is it ethical to provide the answers which you think the tester wants rather than saying what you really feel when taking psychological tests?

LESSON 31 AND 32:
SOFTWARE COST ESTIMATION

Predicting the resources required for a software development process

Objectives

- To introduce the fundamentals of software costing and pricing
- To describe three metrics for software productivity assessment
- To explain why different techniques should be used for software estimation
- To describe the COCOMO 2 algorithmic cost estimation model

Topics Covered

- Productivity
- Estimation techniques
- Algorithmic cost modelling
- Project duration and staffing

Fundamental Estimation Questions

- How much effort is required to complete an activity?
- How much calendar time is needed to complete an activity?
- What is the total cost of an activity?
- Project estimation and scheduling and interleaved management activities

Software Cost Components

- Hardware and software costs
- Travel and training costs
- Effort costs (the dominant factor in most projects)

Salaries of engineers involved in the project

Social and insurance costs

- Effort costs must take overheads into account

Costs of building, heating, lighting

Costs of networking and communications

Costs of shared facilities (e.g. library, staff restaurant, etc

Costing and Pricing

- Estimates are made to discover the cost, to the developer, of producing a software system
- There is not a simple relationship between the development cost and the price charged to the customer
- Broader organisational, economic, political and business considerations influence the price charged

Software Pricing Factors

Factor	Description
Market opportunity	A development organisation may quote a low price because it wishes to move into a new segment of the software market. Accepting a low profit on one project may give the opportunity of more profit later. The experience gained may allow new products to be developed.
Cost estimate uncertainty	If an organisation is unsure of its cost estimate, it may increase its price by some contingency over and above its normal profit.
Contractual terms	A customer may be willing to allow the developer to retain ownership of the source code and reuse it in other projects. The price charged may then be less than if the software source code is handed over to the customer.
Requirements volatility	If the requirements are likely to change, an organisation may lower its price to win a contract. After the contract is awarded, high prices may be charged for changes to the requirements.
Financial health	Developers in financial difficulty may lower their price to gain a contract. It is better to make a small profit or break even than to go out of business.

Programmer Productivity

- A measure of the rate at which individual engineers involved in software development produces software and associated documentation
- Not quality-oriented although quality assurance is a factor in productivity assessment
- Essentially, we want to measure useful functionality produced per time unit

Productivity Measures

- Size related measures based on some output from the software process. This may be lines of delivered source code, object code instructions, etc.
- Function-related measures based on an estimate of the functionality of the delivered software. Function-points are the best known of this type of measure

Measurement Problems

- Estimating the size of the measure
- Estimating the total number of programmer months which have elapsed
- Estimating contractor productivity (e.g. documentation team) and incorporating this estimate in overall estimate

Lines of Code

- What's a line of code?

The measure was first proposed when programs were typed on cards with one line per card

How does this correspond to statements as in Java which can span several lines or where there can be several statements on one line

- What programs should be counted as part of the system?
- Assumes linear relationship between system size and volume of documentation

Productivity Comparisons

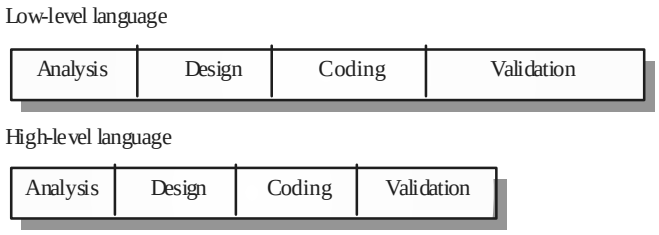
- The lower level the language, the more productive the programmer

The same functionality takes more code to implement in a lower-level language than in a high-level language

- The more verbose the programmer, the higher the productivity

Measures of productivity based on lines of code suggest that programmers who write verbose code are more productive than programmers who write compact code

High And Low Level Languages



System Development Times

	Analysis	Design	Coding	Testing	Documentation
Assembly code	3 weeks	5 weeks	8 weeks	10 weeks	2 weeks
High-level language	3 weeks	5 weeks	8 weeks	6 weeks	2 weeks
	Size	**Effort**	**Productivity**		
Assembly code	5000 lines	28 weeks	714 lines/month		
High-level language	1500 lines	20 weeks	300 lines/month		

Function Points

- Based on a combination of program characteristics

External inputs and outputs

User interactions

External interfaces

Files used by the system

- A weight is associated with each of these
- The function point count is computed by multiplying each raw count by the weight and summing all values
- Function point count modified by complexity of the project
- FPs can be used to estimate LOC depending on the average number of LOC per FP for a given language

LOC = AVC * number of function points

AVC is a language-dependent factor varying from 200-300 for assemble language to 2-40 for a 4GL

- FPs are very subjective. They depend on the estimator.

Automatic function-point counting is impossible

Object Points

- Object points are an alternative function-related measure to function points when 4Gls or similar languages are used for development
- Object points are NOT the same as object classes
- The number of object points in a program is a weighted estimate of

The number of separate screens that are displayed

The number of reports that are produced by the system

The number of 3GL modules that must be developed to supplement the 4GL code

Object Point Estimation

- Object points are easier to estimate from a specification than function points, as they are simply concerned with screens, reports and 3GL modules
- They can therefore be estimated at an early point in the development process. At this stage, it is very difficult to estimate the number of lines of code in a system

Productivity Estimates

- Real-time embedded systems, 40-160 LOC/P-month
- Systems programs, 150-400 LOC/P-month
- Commercial applications, 200-800 LOC/P-month
- In object points, productivity has been measured between 4 and 50 object points/month depending on tool support and developer capability

Factors Affecting Productivity

Factor	Description
Application domain experience	Knowledge of the application domain is essential for effective software development. Engineers who already understand a domain are likely to be the most productive.
Process quality	The development process used can have a significant effect on productivity. This is covered in Chapter 31.
Project size	The larger a project, the more time required for team communications. Less time is available for development so individual productivity is reduced.
Technology support	Good support technology such as CASE tools, supportive configuration management systems, etc. can improve productivity.
Working environment	As discussed in Chapter 28, a quiet working environment with private work areas contributes to improved productivity.

Quality and Productivity

- All metrics based on volume/unit time are flawed because they do not take quality into account
- Productivity may generally be increased at the cost of quality
- It is not clear how productivity/quality metrics are related
- If change is constant then an approach based on counting lines of code is not meaningful

Estimation Techniques

- There is no simple way to make an accurate estimate of the effort required to develop a software system

Initial estimates are based on inadequate information in a user requirements definition

The software may run on unfamiliar computers or use new technology

The people in the project may be unknown

- Project cost estimates may be self-fulfilling

The estimate defines the budget and the product is adjusted to meet the budget

- Algorithmic cost modelling
- Expert judgement
- Estimation by analogy
- Parkinson's Law
- Pricing to win

Algorithmic Code Modelling

- A formulaic approach based on historical cost information and which is generally based on the size of the software

Expert Judgement

- One or more experts in both software development and the application domain use their experience to predict software costs. Process iterates until some consensus is reached.
- Advantages: Relatively cheap estimation method. Can be accurate if experts have direct experience of similar systems
- Disadvantages: Very inaccurate if there are no experts!

Estimation by Analogy

- The cost of a project is computed by comparing the project to a similar project in the same application domain
- Advantages: Accurate if project data available
- Disadvantages: Impossible if no comparable project has been tackled. Needs systematically maintained cost database

Parkinson's Law

- The project costs whatever resources are available
- Advantages: No overspend
- Disadvantages: System is usually unfinished

Pricing to Win

- The project costs whatever the customer has to spend on it
- Advantages: You get the contract
- Disadvantages: The probability that the customer gets the system he or she wants is small. Costs do not accurately reflect the work required

Top-down and Bottom-up Estimation

- Any of these approaches may be used top-down or bottom-up
- Top-down

Start at the system level and assess the overall system functionali ty and how this is delivered through sub-systems

- Bottom-up

Start at the component level and estimate the effort required for each component. Add these efforts to reach a final estimate

Top-down Estimation

- Usable without knowledge of the system architecture and the components that might be part of the system
- Takes into account costs such as integration, configuration management and documentation
- Can underestimate the cost of solving difficult low-level technical problems

Bottom-up Estimation

- Usable when the architecture of the system is known and components identified
- Accurate method if the system has been designed in detail
- May underestimate costs of system level activities such as integration and documentation

Estimation Methods

- Each method has strengths and weaknesses
- Estimation should be based on several methods
- If these do not return approximately the same result, there is insufficient information available
- Some action should be taken to find out more in order to make more accurate estimates
- Pricing to win is sometimes the only applicable method

Experience-based Estimates

- Estimating is primarily experience-based
- However, new methods and technologies may make estimating based on experience inaccurate

Object oriented rather than function-oriented development

Client-server systems rather than mainframe systems

Off the shelf components

Component-based software engineering

CASE tools and program generators

Pricing to Win

- This approach may seem unethical and unbusinesslike
- However, when detailed information is lacking it may be the only appropriate strategy
- The project cost is agreed on the basis of an outline proposal and the development is constrained by that cost
- A detailed specification may be negotiated or an evolutionary approach used for system development

Algorithmic Cost Modelling

- Cost is estimated as a mathematical function of product, project and process attributes whose values are estimated by project managers

Effort = A ´ SizeB ´ M

A is an organisation-dependent constant, B reflects the disproportionate effort for large projects and M is a multiplier reflecting product, process and people attributes

- Most commonly used product attribute for cost ”estimation is code size
- Most models are basically similar but with different values for A, B and M

Estimation Accuracy

- The size of a software system can only be known accurately when it is finished
- Several factors influence the final size

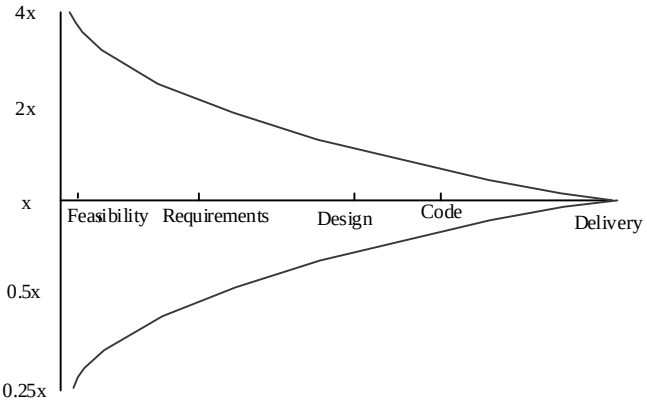
Use of COTS and components

Programming language

Distribution of system

- As the development process progresses then the size estimate becomes more accurate

Estimate Uncertainty



The COCOMO Model

- An empirical model based on project experience
- Well-documented, ‘independent’ model, which is not tied to a specific software vendor
- Long history from initial version published in 1981 (COCOMO-81) through various instantiations to COCOMO 2
- COCOMO 2 takes into account different approaches to software development, reuse, etc.

COCOMO 81

Project complexity	Formula	Description
Simple	$PM = 2.4\ (KDSI)^{1.05} \times M$	Well-understood applications developed by small teams.
Moderate	$PM = 3.0\ (KDSI)^{1.12} \times M$	More complex projects where team members may have limited experience of related systems.
Embedded	$PM = 3.6\ (KDSI)^{1.20} \times M$	Complex projects where the software is part of a strongly coupled complex of hardware, software, regulations and operational procedures.

COCOMO 2 levels

- COCOMO 2 is a 3 level model that allows increasingly detailed estimates to be prepared as development progresses
- Early prototyping level

Estimates based on object points and a simple formula is used for effort estimation

- Early design level

Estimates based on function points that are then translated to LOC

- Post-architecture level

Estimates based on lines of source code

Early Prototyping Level

- Supports prototyping projects and projects where there is extensive reuse
- Based on standard estimates of developer productivity in object points/month
- Takes CASE tool use into account
- Formula is

PM = (NOP ´ (1 - %reuse/100)) / PROD•PM is the effort in person-months, NOP is the number of object points and PROD is the productivity

Object Point Productivity

Developer’s experience and capability	Very low	Low	Nominal	High	Very high
ICASE maturity and capability	Very low	Low	Nominal	High	Very high
PROD (NOP/month)	4	7	13	25	50

Early Design Level

- Estimates can be made after the requirements have been agreed
- Based on standard formula for algorithmic models

PM = A ´ SizeB ´ M + PMm where

M = PERS ´ RCPX ´ RUSE ´ PDIF ´ PREX ´ FCIL ´ SCED

PMm = (ASLOC ´ (AT/100)) / ATPROD•A = 2.5 in initial calibration, Size in KLOC, B varies from 1.1 to 1.24 depending on novelty of the project, development flexibility, risk management approaches and the process maturity

Multipliers

- Multipliers reflect the capability of the developers, the non-functional requirements, the familiarity with the development platform, etc.

RCPX - product reliability and complexity

RUSE - the reuse required

PDIF - platform difficulty

PREX - personnel experience

PERS - personnel capability

SCED - required schedule

FCIL - the team support facilities

- PM reflects the amount of automatically generated code

Post-architecture Level

- Uses same formula as early design estimates
- Estimate of size is adjusted to take into account

Requirements volatility. Rework required to support change

Extent of possible reuse. Reuse is non-linear and has associated costs so this is not a simple reduction in LOC

ESLOC = ASLOC ´ (AA + SU +0.4DM + 0.3CM +0.3IM)/ 100

»ESLOC is equivalent number of lines of new code. ASLOC is the number of lines of reusable code which must be modified, DM is the percentage of design modified, CM is the percentage of the code that is modified, IM is the percentage of the original integration effort required for integrating the reused software.

»SU is a factor based on the cost of software understanding; AA is a factor, which reflects the initial assessment costs of deciding if software may be reused.

The Exponent Term

- This depends on 5 scale factors (see next slide). Their sum/ 100 is added to 1.01
- Example

Precedent ness - new project - 4

Development flexibility - no client involvement - Very high - 1

Architecture/risk resolution - No risk analysis - V. Low - 5

Team cohesion - new team - nominal - 3

Process maturity - some control - nominal - 3

Scale factor is therefore 1.17

Exponent Scale Factors

Scale factor	Explanation
Precedentedness	Reflects the previous experience of the organisation with this type of project. Very low means no previous experience, Extra high means that the organisation is completely familiar with this application domain.
Development flexibility	Reflects the degree of flexibility in the development process. Very low means a prescribed process is used; Extra high means that the client only sets general goals.
Architecture/risk resolution	Reflects the extent of risk analysis carried out. Very low means little analysis, Extra high means a complete a thorough risk analysis.
Team cohesion	Reflects how well the development team know each other and work together. Very low means very difficult interactions, Extra high means an integrated and effective team with no communication problems.
Process maturity	Reflects the process maturity of the organisation. The computation of this value depends on the CMM Maturity Questionnaire but an estimate can be achieved by subtracting the CMM process maturity level from 5.

Multipliers

- Product attributes

Concerned with required characteristics of the software product being developed

- Computer attributes

Constraints imposed on the software by the hardware platform

- Personnel attributes

Multipliers that take the experience and capabilities of the people working on the project into account.

- Project attributes

Concerned with the particular characteristics of the software development project

Project Cost Drivers

Product attributes			
RELY	Required system reliability	DATA	Size of database used
CPLX	Complexity of system modules	RUSE	Required percentage of reusable components
DOCU	Extent of documentation required		
Computer attributes			
TIME	Execution time constraints	STOR	Memory constraints
PVOL	Volatility of development platform		
Personnel attributes			
ACAP	Capability of project analysts	PCAP	Programmer capability
PCON	Personnel continuity	AEXP	Analyst experience in project domain
PEXP	Programmer experience in project domain	LTEX	Language and tool experience
Project attributes			
TOOL	Use of software tools	SITE	Extent of multi-site working and quality of site communications
SCED	Development schedule compression		

Project Planning

- Algorithmic cost models provide a basis for project planning as they allow alternative strategies to be compared
- Embedded spacecraft system

Must be reliable

Must minimise weight (number of chips)

Multipliers on reliability and computer constraints > 1

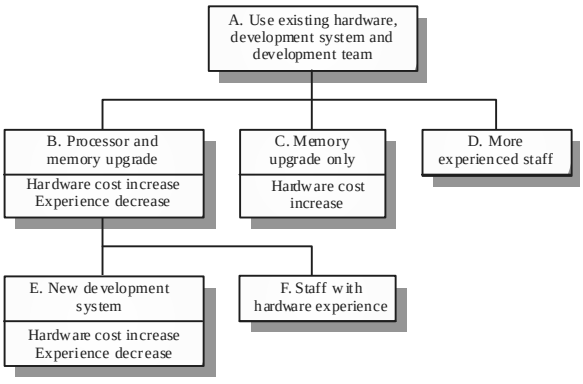
- Cost components

Target hardware

Development platform

Effort required

Management Options


A. Use existing hardware, development system and development team
B. Processor and memory upgrade
Hardware cost increase
Experience decrease
C. Memory upgrade only
Hardware cost increase
D. More experienced staff
E. New development system
Hardware cost increase
Experience decrease
F. Staff with hardware experience

Management Options Costs

Option	RELY	STOR	TIME	TOOLS	LTEX	Total effort	Software cost	Hardware cost	Total cost
A	1.39	1.06	1.11	0.86	1	63	949393	100000	1049393
B	1.39	1	1	1.12	1.22	88	1313550	120000	1402025
C	1.39	1	1.11	0.86	1	60	895653	105000	1000653
D	*1.39*	*1.06*	*1.11*	*0.86*	*0.84*	*51*	*769008*	*100000*	*897490*
E	1.39	1	1	0.72	1.22	56	844425	220000	1044159
F	1.39	1	1	1.12	0.84	57	851180	120000	1002706

Option Choice

- Option D (use more experienced staff) appears to be the best alternative

However, it has a high associated risk, as experienced staff may be difficult to find

- Option C (upgrade memory) has a lower cost saving but very low risk
- Overall, the model reveals the importance of staff experience in software development

Project Duration and Staffing

- As well as effort estimation, managers must estimate the calendar time required to complete a project and when staff will be required
- Calendar time can be estimated using a COCOMO 2 formula

TDEV = 3 ´ (PM)(0.33+0.2*(B-1.01))

PM is the effort computation and B is the exponent computed as discussed above (B is 1 for the early prototyping model). This computation predicts the nominal schedule for the project

- The time required is independent of the number of people working on the project

Staffing Requirements

- Staff required can't be computed by diving the development time by the required schedule
- The number of people working on a project varies depending on the phase of the project
- The more people who work on the project, the more total effort is usually required
- A very rapid build-up of people often correlates with schedule slippage

Key Points

- Factors affecting productivity include individual aptitude, domain experience, the development project, the project size, tool support and the working environment
- Different techniques of cost estimation should be used when estimating costs
- Software may be priced to gain a contract and the functionality adjusted to the price
- Algorithmic cost estimation is difficult because of the need to estimate attributes of the finished product
- The COCOMO model takes project, product, personnel and hardware attributes into account when predicting effort required
- Algorithmic cost models support quantitative option analysis
- The time to complete a project is not proportional to the number of people working on the project

Activity

Describe two metrics that have been used to measure programmer productivity. Comment briefly on the advantages and disadvantages of these metrics.

Activity

Cost estimates are inherently risky irrespective of the estimation technique used. Suggest four ways in which the risk in a cost estimate can be reduced.

Activity

Give three reasons why algorithmic cost estimates prepared in different organizations are not directly comparable.

Activity

Explain how the algorithmic approach to cost estimation may be used by project mangers for option analysis. Suggest a situation where mangers may choose an approach that is not based on the lowest project cost.

Activity

Implement the COCOMO model using a spreadsheet such as Microsoft excel. Details of the model can be downloaded form the COCOMO2 web site.

Activity

Some very large software projects involve the writing of millions of lines of code. Suggest how useful the cost estimation models are likely to be for such systems. Why might the assumptions on which they are based be invalid for very large software system?

Activity

Is it ethical for a company to quote a low price for a software contract knowing that the requirements are ambiguous and that they can charge a high price for subsequent changes requested by the customer?

Activity

Should measured productivity be used by managers during the staff appraisal process? What safeguards are necessary to ensure that quality is not affected by this?

Notes:

LESSON 33 AND 34: QUALITY MANAGEMENT

Managing the Quality of the Software Process and Products

Objectives

- To introduce the quality management process and key quality management activities
- To explain the role of standards in quality management
- To explain the concept of a software metric, predictor metrics and control metrics
- To explain how measurement may be used in assessing software quality

Topics Covered

- Quality assurance and standards
- Quality planning
- Quality control
- Software measurement and metrics

Software Quality Management

- Concerned with ensuring that the required level of quality is achieved in a software product
- Involves defining appropriate quality standards and procedures and ensuring that these are followed
- Should aim to develop a 'quality culture' where quality is seen as everyone's responsibility

What is Quality?

- Quality, simplistically, means that a product should meet its specification
- This is problematical for software systems

Tension between customer quality requirements (efficiency, reliability, etc.) and developer quality requirements (maintainability, reusability, etc.)

Some quality requirements are difficult to specify in an unambiguous way

Software specifications are usually incomplete and often inconsistent

The Quality Compromise

- We cannot wait for specifications to improve before paying attention to quality management
- Must put procedures into place to improve quality in spite of imperfect specification
- Quality management is therefore not just concerned with reducing defects but also with other product qualities

Quality Management Activities

- Quality assurance

Establish organisational procedures and standards for quality

- Quality planning

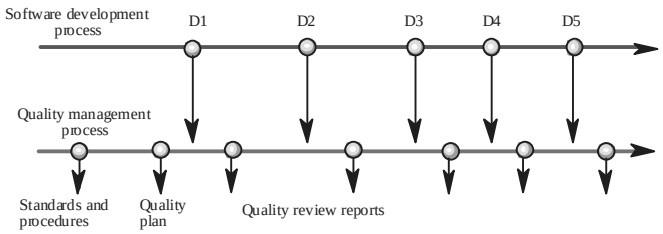
Select applicable procedures and standards for a particular project and modify these as required

- Quality control

Ensure that procedures and standards are followed by the software development team

- Quality management should be separate from project management to ensure independence

Quality Management and Software Development



ISO 9000

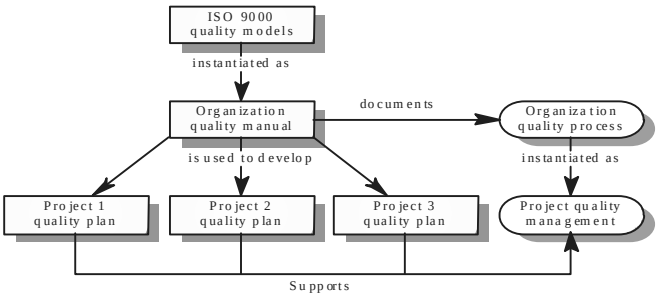
- International set of standards for quality management
- Applicable to a range of organisations from manufacturing to service industries
- ISO 9001 applicable to organisations, which design, develops and maintains products
- ISO 9001 is a generic model of the quality process must be instantiated for each organisation

Management responsibility	Quality system
Control of non-conforming products	Design control
Handling, storage, packaging and delivery	Purchasing
Purchaser-supplied products	Product identification and traceability
Process control	Inspection and testing
Inspection and test equipment	Inspection and test status
Contract review	Corrective action
Document control	Quality records
Internal quality audits	Training
Servicing	Statistical techniques

ISO 9000 Certification

- Quality standards and procedures should be documented in an organisational quality manual
- External body may certify that an organisation's quality manual conforms to ISO 9000 standards
- Customers are, increasingly, demanding that suppliers are ISO 9000 certified

ISO 9000 and Quality Management



Quality Assurance and Standards

- Standards are the key to effective quality management
- They may be international, national, and organizational or project standards
- Product standards define characteristics that all components should exhibit e.g. a common programming style
- Process standards define how the software process should be enacted

Importance of Standards

- Encapsulation of best practice: avoids repetition of past mistakes
- Framework for quality assurance process : it involves checking standard compliance
- Provide continuity : new staff can understand the organisation by understand the standards applied

Product and Process Standards

Product standards	Process standards
Design review form	Design review conduct
Document naming standards	Submission of documents to CM
Procedure header format	Version release process
Ada programming style standard	Project plan approval process
Project plan format	Change control process
Change request form	Test recording process

Problems with Standards

- Not seen as relevant and up-to-date by software engineers
- Involve too much bureaucratic form filling
- Unsupported by software tools so tedious manual work is involved to maintain standards

Standards Development

- Involve practitioners in development. Engineers should understand the rationale underlying a standard
- Review standards and their usage regularly. Standards can quickly become outdated and this reduces their credibility amongst practitioners
- Detailed standards should have associated tool support. Excessive clerical work is the most significant complaint against standards

Documentation Standards

- Particularly important : documents are the tangible manifestation of the software
- Documentation process standards

How documents should be developed, validated and maintained

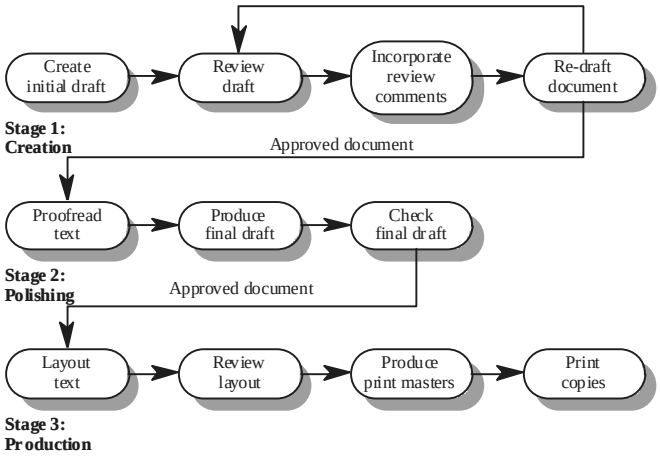
- Document standards

Concerned with document contents, structure, and appearance

- Document interchange standards

How documents are stored and interchanged between different documentation systems

Documentation Process



Document Standards

Document identification standards

How documents are uniquely identified

- Document structure standards

Standard structure for project documents

- Document presentation standards

Define fonts and styles use of logos, etc.

- Document update standards

Define how changes from previous versions are reflected in a document

Document Interchange Standards

- Documents are produced using different systems and on different computers
- Interchange standards allow electronic documents to be exchanged, mailed, etc.
- Need for archiving. The lifetime of word processing systems may be much less than the lifetime of the software being documented
- XML is an emerging standard for document interchange, which will be widely supported in future

Process and Product Quality

- The quality of a developed product is influenced by the quality of the production process
- Particularly important in software development as some product quality attributes are hard to assess
- However, there is a very complex and poorly understood between software processes and product quality

Process-based Quality

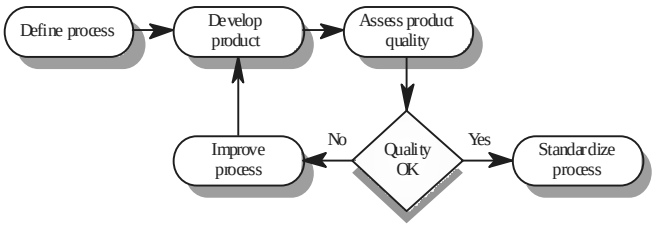
- Straightforward link between process and product in manufactured goods
- More complex for software because:

The application of individual skills and experience is particularly important in software development

External factors such as the novelty of an application or the need for an accelerated development schedule may impair product quality

- Care must be taken not to impose inappropriate process standards

Process-based Quality



Practical Process Quality

- Define process standards such as how reviews should be conducted, configuration management, etc.
- Monitor the development process to ensure that standards are being followed
- Report on the process to project management and software procurer

Quality Planning

- A quality plan sets out the desired product qualities and how these are assessed and define the most significant quality attributes
- It should define the quality assessment process
- It should set out which organisational standards should be applied and, if necessary, define new standards

Quality Plan Structure

- Product introduction
- Product plans
- Process descriptions
- Quality goals
- Risks and risk management
- Quality plans should be short, succinct documents

If they are too long, no one will read them

Software Quality Attributes

Safety	Understandability	Portability
Security	Testability	Usability
Reliability	Adaptability	Reusability
Resilience	Modularity	Efficiency
Robustness	Complexity	Learnability

Quality Control

- Checking the software development process to ensure that procedures and standards are being followed
- Two approaches to quality control

Quality reviews

Automated software assessment and software measurement

Quality Reviews

- The principal method of validating the quality of a process or of a product
- Group examined part or all of a process or system and its documentation to find potential problems
- There are different types of review with different objectives

Inspections for defect removal (product)

Reviews for progress assessment (product and process)

Quality reviews (product and standards)

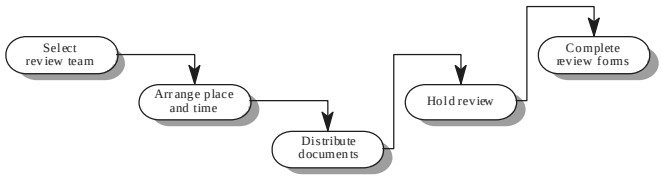
Types of Review

Review type	**Principal purpose**
Design or program inspections	To detect detailed errors in the design or code and to check whether standards have been followed. The review should be driven by a checklist of possible errors.
Progress reviews	To provide information for management about the overall progress of the project. This is both a process and a product review and is concerned with costs, plans and schedules.
Quality reviews	To carry out a technical analysis of product components or documentation to find faults or mismatches between the specification and the design, code or documentation. It may also be concerned with broader quality issues such as adherence to standards and other quality attributes.

Quality Reviews

- A group of people carefully examine part or all of a software system and its associated documentation.
- Code, designs, specifications, test plans, standards, etc. can all be reviewed.
- Software or documents may be 'signed off' at a review, which signifies that progress to the next development stage has been approved by management.

The Review Process



Review Functions

- Quality function : They are part of the general quality management process
- Project management function : They provide information for project managers
- Training and communication function - product knowledge is passed between development team members

Quality Reviews

- Objective is the discovery of system defects and inconsistencies
- Any documents produced in the process may be reviewed
- Review teams should be relatively small and reviews should be fairly short
- Review should be recorded and records maintained

Review Results

- Comments made during the review should be classified.

No action : No change to the software or documentation is required.

Refer for repair : Designer or programmer should correct an identified fault.

Reconsider overall design : The problem identified in the review impacts other parts of the design. Some overall judgement must be made about the most cost-effective way of solving the problem.

- Requirements and specification errors may have to be referred to the client.

Software Measurement and Metrics

- Software measurement is concerned with deriving a numeric value for an attribute of a software product or process
- This allows for objective comparisons between techniques and processes
- Although some companies have introduced measurement programmes, the systematic use of measurement is still uncommon
- There are few standards in this area

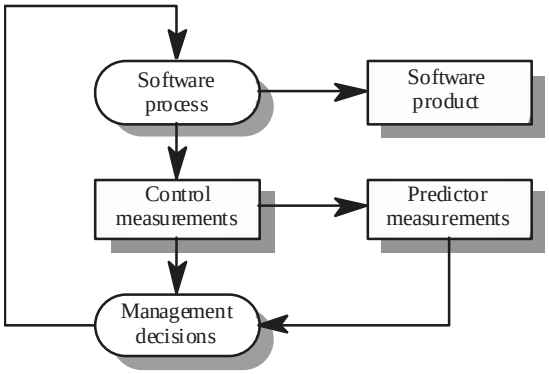
Software Metric

- Any type of measurement, which relates to a software system, process or related documentation

Lines of code in a program, the Fog index, and number of person-days required to develop a component

- Allow the software and the software process to be quantified
- Measures of the software process or product
- May be used to predict product attributes or to control the software process

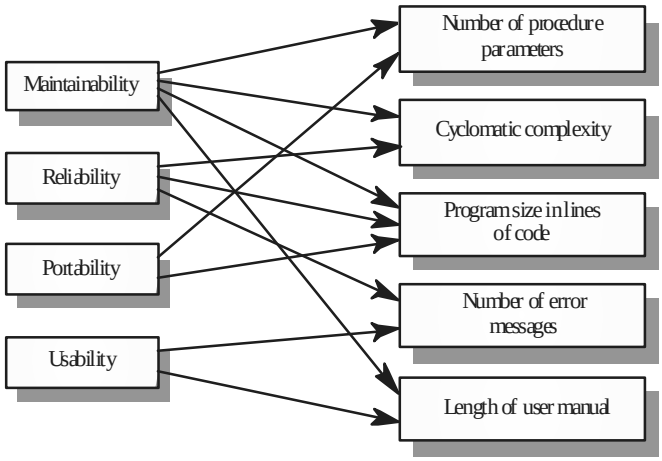
Predictor and Control Metrics



Metrics Assumptions

- A software property can be measured
- The relationship exists between what we can measure and what we want to know
- This relationship has been formalized and validated
- It may be difficult to relate what can be measured to desirable quality attributes

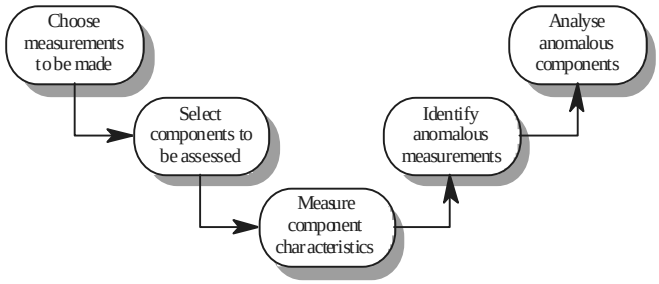
Internal and External Attributes



The Measurement Process

- A software measurement process may be part of a quality control process
- Data collected during this process should be maintained as an organisational resource
- Once a measurement database has been established, comparisons across projects become possible

Product Measurement Process



Data Collection

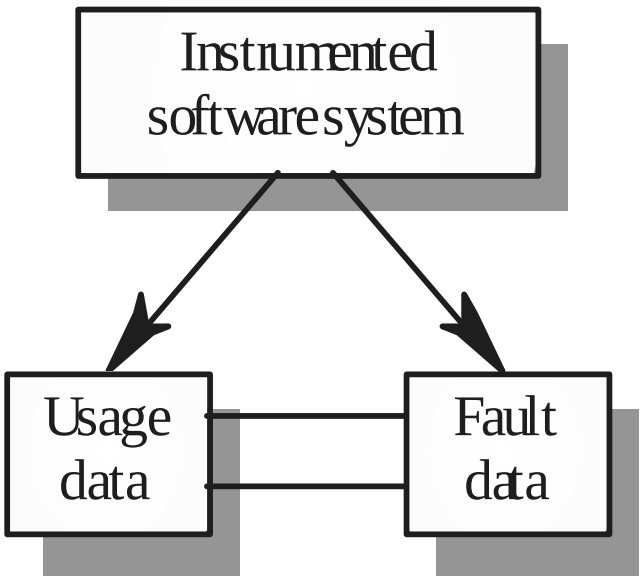
- A metrics programme should be based on a set of product and process data
- Data should be collected immediately (not in retrospect) and, if possible, automatically
- Three types of automatic data collection

Static product analysis

Dynamic product analysis

Process data collation

Automated Data Collection



Data Accuracy

- Don't collect unnecessary data

The questions to be answered should be decided in advance and the required data identified

- Tell people why the data is being collected

It should not be part of personnel evaluation

- Don't rely on memory

Collect data when it is generated not after a project has finished

Product Metrics

- A quality metric should be a predictor of product quality
- Classes of product metric

Dynamic metrics, which are collected by measurements, made of a program in execution

Static metrics, which are collected by measurements, made of the system representations

Dynamic metrics help assess efficiency and reliability; static metrics help assess complexity, understandability and maintainability

Dynamic and Static Metrics

- Dynamic metrics are closely related to software quality attributes

It is relatively easy to measure the response time of a system (performance attribute) or the number of failures (reliability attribute)

- Static metrics have an indirect relationship with quality attributes

You need to try and derive a relationship between these metrics and properties such as complexity, understandability and maintainability

Software Product Metrics

Software metric	Description
Fan in/Fan-out	Fan-in is a measure of the number of functions that call some other function (say X). Fan-out is the number of functions which are called by function X. A high value for fan-in means that X is tightly coupled to the rest of the design and changes to X will have extensive knock-on effects. A high value for fan-out suggests that the overall complexity of X may be high because of the complexity of the control logic needed to coordinate the called components.
Length of code	This is a measure of the size of a program. Generally, the larger the size of the code of a program's components, the more complex and error-prone that component is likely to be.
Cyclomatic complexity	This is a measure of the control complexity of a program. This control complexity may be related to program understandability. The computation of cyclomatic complexity is covered in Chapter 20.
Length of identifiers	This is a measure of the average length of distinct identifiers in a program. The longer the identifiers, the more likely they are to be meaningful and hence the more understandable the program.
Depth of conditional nesting	This is a measure of the depth of nesting of if-statements in a program. Deeply nested if statements are hard to understand and are potentially error-prone.
Fog index	This is a measure of the average length of words and sentences in documents. The higher the value for the Fog index, the more difficult the document may be to understand.

Object-oriented Metrics

Object-oriented metric	Description
Depth of inheritance tree	This represents the number of discrete levels in the inheritance tree where sub-classes inherit attributes and operations (methods) from super-classes. The deeper the inheritance tree, the more complex the design as, potentially, many different object classes have to be understood to understand the object classes at the leaves of the tree.
Method fan-in/fan-out	This is directly related to fan-in and fan-out as described above and means essentially the same thing. However, it may be appropriate to make a distinction between calls from other methods within the object and calls from external methods.
Weighted methods per class	This is the number of methods included in a class weighted by the complexity of each method. Therefore, a simple method may have a complexity of 1 and a large and complex method a much higher value. The larger the value for this metric, the more complex the object class. Complex objects are more likely to be more difficult to understand. They may not be logically cohesive so cannot be reused effectively as super-classes in an inheritance tree.
Number of overriding operations	These are the number of operations in a super-class which are over-ridden in a sub-class. A high value for this metric indicates that the super-class used may not be an appropriate parent for the sub-class.

Measurement Analysis

- It is not always obvious what data means

Analysing collected data is very difficult

- Professional statisticians should be consulted if available
- Data analysis must take local circumstances into account

Measurement Surprises

- Reducing the number of faults in a program leads to an increased number of help desk calls

The program is now thought of as more reliable and so has a wider more diverse market. The percentage of users who call the help desk may have decreased but the total may increase

A more reliable system is used in a different way from a system where users work around the faults. This leads to more help desk calls

Key Points

- Software quality management is concerned with ensuring that software meets its required standards
- Quality assurance procedures should be documented in an organisational quality manual
- Software standards are an encapsulation of best practice
- Reviews are the most widely used approach for assessing software quality
- Software measurement gathers information about both the software process and the software product
- Product quality metrics should be used to identify potentially problematical components
- There are no standardised and universally applicable software metrics

Activity

Explain why a high-quality software process should lead to high quality software products. Discuss possible problems with this system of quality management.

Activity

What are the stages involved in the review of a software design?

Activity

Briefly describe possible standards which might be used for:

- The use of control constructs in C, C++ OR Java.
- Reports which might be submitted for a term project in a university:
- The process of purchasing and installing a new computer.

Activity

Explain why design metrics are, by themselves, an inadequate method of predicting design quality.

Activity

A colleague who is a very good programmer produces software with a low number of defects but consistently ignores organizational quality standards. How should the managers in the organization react to this behaviour?

Notes:

LESSON 35:
PROCESS IMPROVEMENT

Understanding, Modelling and Improving the Software Process

Objectives

- To explain the principles of software process improvement
- To explain how software process factors influence software quality and productivity
- To introduce the SEI Capability Maturity Model and to explain why it is influential. To discuss the applicability of that model
- To explain why CMM-based improvement is not universally applicable

Topics Covered

- Process and product quality
- Process analysis and modelling
- Process measurement
- The SEI process maturity model
- Process classification

Process Improvement

- Understanding existing processes
- Introducing process changes to achieve organisational objectives, which are usually focused on quality improvement, cost reduction and schedule acceleration
- Most process improvement work so far has focused on defect reduction. This reflects the increasing attention paid by industry to quality
- However, other process attributes can be the focus of improvement

Process Attributes

Process characteristic	Description
Understandability	To what extent is the process explicitly defined and how easy is it to understand the process definition?
Visibility	Do the process activities culminate in clear results so that the progress of the process is externally visible?
Supportability	To what extent can the process activities be supported by CASE tools?
Acceptability	Is the defined process acceptable to and usable by the engineers responsible for producing the software product?
Reliability	Is the process designed in such a way that process errors are avoided or trapped before they result in product errors?
Robustness	Can the process continue in spite of unexpected problems?
Maintainability	Can the process evolve to reflect changing organisational requirements or identified process improvements?
Rapidity	How fast can the process of delivering a system from a given specification be completed?

Process Improvement Stages

- Process analysis

Model and analyse (quantitatively if possible) existing processes

- Improvement identification

Identify quality, cost or schedule bottlenecks

- Process change introduction

Modify the process to remove identified bottlenecks

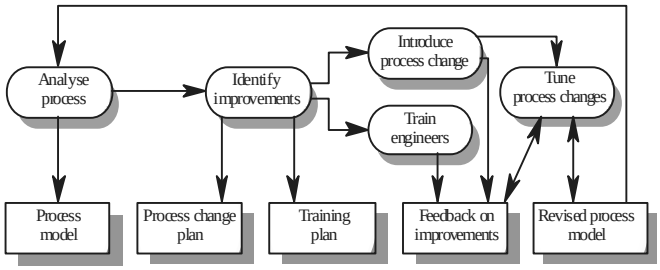
- Process change training

Train staff involved in new process proposals

- Change tuning

Evolve and improve process improvements

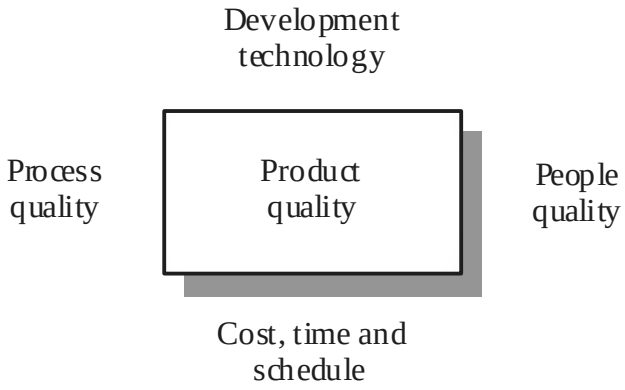
The Process Improvement Process



Process and Product Quality

- Process quality and product quality are closely related
- A good process is usually required to produce a good product
- For manufactured goods, process is the principal quality determinant
- For design-based activity, other factors are also involved especially the capabilities of the designers

Principal Product Quality Factors



Quality Factors

- For large projects with 'average' capabilities, the development process determines product quality
- For small projects, the capabilities of the developers is the main determinant

- The development technology is particularly significant for small projects
- In all cases, if an unrealistic schedule is imposed then product quality will suffer

Process Analysis and Modelling

- Process analysis

The study of existing processes to understand the relationships between parts of the process and to compare them with other processes

- Process modelling

The documentation of a process, which records the tasks, the roles and the entities, used

Process models may be presented from different perspectives

- Study an existing process to understand its activities
- Produce an abstract model of the process. You should normally represent this graphically. Several different views (e.g. activities, deliverables, etc.) may be required
- Analyse the model to discover process problems. Involves discussing activities with stakeholders

Process Analysis Techniques

- Published process models and process standards

It is always best to start process analysis with an existing model. People then may extend and change this.

- Questionnaires and interviews

Must be carefully designed. Participants may tell you what they think you want to hear

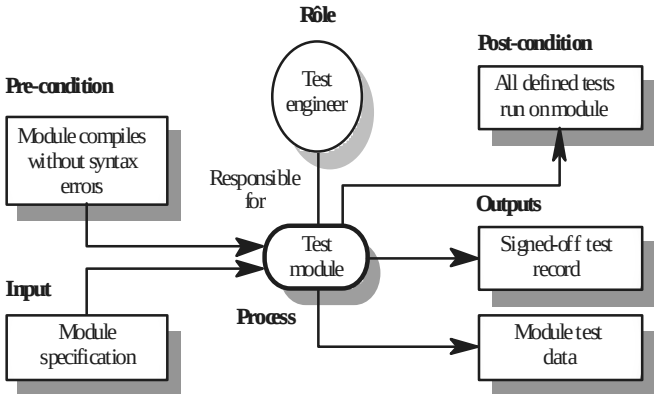
- Ethnographic analysis

Involves assimilating process knowledge by observation

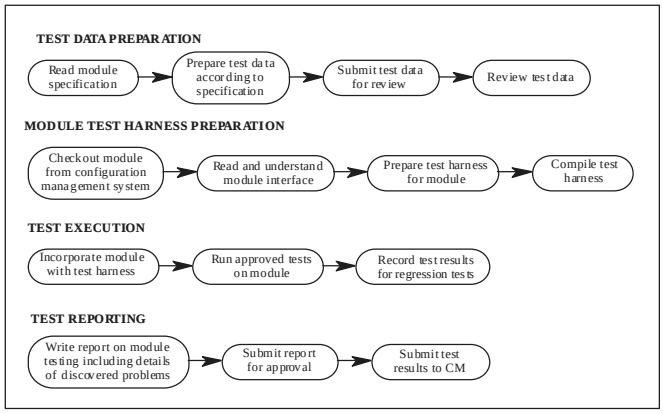
Elements of a Process Model

Process model element	Description
Activity (represented by a round-edged rectangle with no drop shadow)	An activity has a clearly defined objective, entry and exit conditions. Examples of activities are preparing a set of test data to test a module, coding a function or a module, proof-reading a document, etc. Generally, an activity is atomic i.e. it is the responsibility of one person or group. It is not decomposed into sub-activities.
Process (represented by a round-edged rectangle with drop shadow)	A process is a set of activities which have some coherence and whose objective is generally agreed within an organisation. Examples of processes are requirements analysis, architectural design, test planning, etc.
Deliverable (represented by a rectangle with drop shadow)	A deliverable is a tangible output of an activity which is predicted in a project plan.
Condition (represented by a parallelogram)	A condition is either a pre-condition which must hold before a process or activity can start or a post-condition which holds after a process or activity has finished.
Role (represented by a circle with drop shadow)	A role is a bounded area of responsibility. Examples of roles might be configuration manager, test engineer, software designer, etc. One person may have several different roles and a single role may be associated with several different people.
Exception (not shown in examples here but may be represented as a double edged box)	An exception is a description of how to modify the process if some anticipated or unanticipated event occurs. Exceptions are often undefined and it is left to the ingenuity of the project managers and engineers to handle the exception.
Communication (represented by an arrow)	An interchange of information between people or between people and supporting computer systems. Communications may be informal or formal. Formal communications might be the approval of a deliverable by a project manager; informal communications might be the interchange of electronic mail to resolve ambiguities in a document.

The Module Testing Activity



Activities in Module Testing


TEST DATA PREPARATION
Read module specification
Prepare test data according to specification
Submit test data for review
Review test data
MODULE TEST HARNESS PREPARATION
Checkout module from configuration management system
Read and understand module interface
Prepare test harness for module
Compile test harness
TEST EXECUTION
Incorporate module with test harness
Run approved tests on module
Record test results for regression tests
TEST REPORTING
Write report on module testing including details of discovered problems
Submit report for approval
Submit test results to CM

Process Exceptions

- Software processes are complex and process models cannot effectively represent how to handle exceptions

Several key people becoming ill just before a critical review

A complete failure of a communication processor so that no e-mail is available for several days

Organisational reorganisation

A need to respond to an unanticipated request for new proposals

- Under these circumstances, the model is suspended and managers use their initiative to deal with the exception

Process Measurement

- Wherever possible, quantitative process data should be collected

However, where organisations do not have clearly defined process standards this is very difficult, as you don't know what to measure. A process may have to be defined before any measurement is possible

- Process measurements should be used to assess process improvements

But this does not mean that measurements should drive the improvements. The improvement driver should be the organizational objectives

Classes of Process Measurement

- Time taken for process activities to be completed

E.g. Calendar time or effort to complete an activity or process

- Resources required for processes or activities

E.g. Total effort in person-days

- Number of occurrences of a particular event

E.g. Number of defects discovered

Goal-Question-Metric Paradigm

- Goals

What is the organisation trying to achieve? The objective of process improvement is to satisfy these goals

- Questions

Questions about areas of uncertainty related to the goals. You need process knowledge to derive these

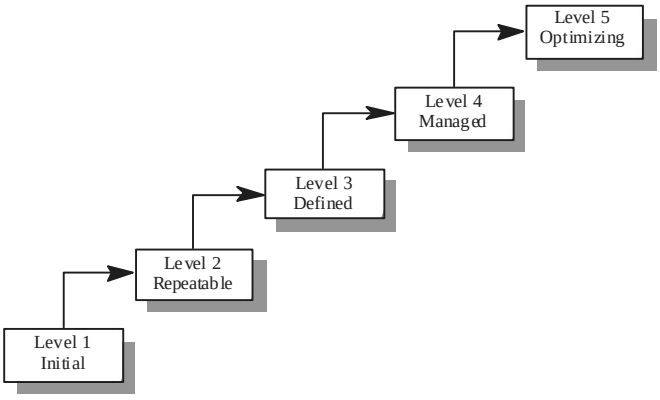
- Metrics

Measurements to be collected to answer the questions

The Software Engineering Institute

- US Defence Dept. funded institute associated with Carnegie Mellon
- Mission is to promote software technology transfer particularly to defence contractors
- Maturity model proposed in mid-1980s, refined in early 1990s.
- Work has been very influential in process improvement

The SEI Process Maturity Model



Maturity Model Levels

- Initial

Essentially uncontrolled

- Repeatable

Product management procedures defined and used

- Defined

Process management procedures and strategies defined and used

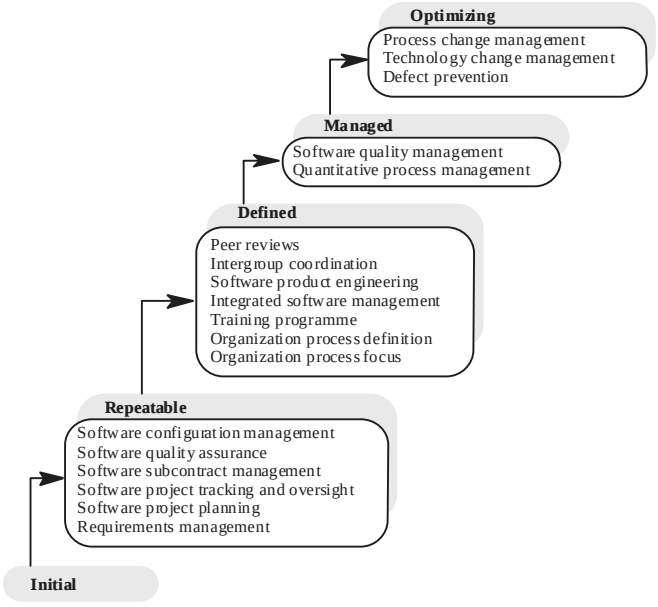
- Managed

Quality management strategies defined and used

- Optimising

Process improvement strategies defined and used

Key Process Areas



SEI Model Problems

- It focuses on project management rather than product development.
- It ignores the use of technologies such as rapid prototyping.
- It does not incorporate risk analysis as a key process area
- It does not define its domain of applicability

The CMM and ISO 9000

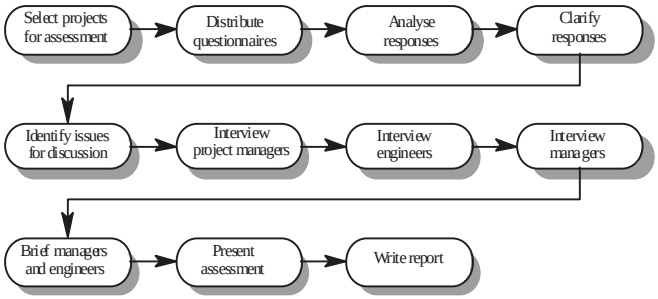
- There is a clear correlation between the key processes in the CMM and the quality management processes in ISO 9000
- The CMM is more detailed and prescriptive and includes a framework for improvement
- Organisations rated as level 2 in the CMM are likely to be ISO 9000 compliant

Capability Assessment

- An important role of the SEI is to use the CMM to assess the capabilities of contractors bidding for US government defence contracts
- The model is intended to represent organisational capability not the practices used in particular projects
- Within the same organisation, there are often wide variations in processes used

- Capability assessment is questionnaire-based

The Capability Assessment Process



Process Classification

- Informal

No detailed process model. Development team chose their own way of working

- Managed

Defined process model, which drives the development process

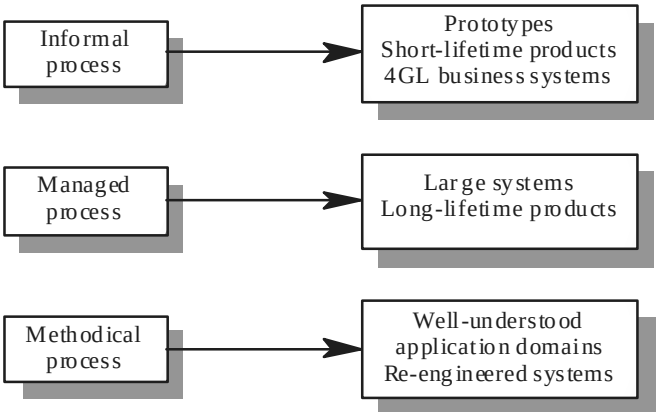
- Methodical

Processes supported by some development method such as HOOD

- Supported

Processes supported by automated CASE tools

Process Applicability



Process Choice

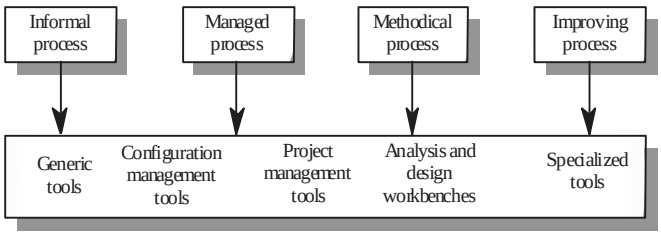
- Process used should depend on type of product, which is being developed

For large systems, management are usually the principal problem so you need a strictly managed process. For smaller systems, more informality is possible.

- There is no uniformly applicable process, which should be standardised within an organisation

High costs may be incurred if you force an inappropriate process on a development team

Process Tool Support



Key Points

- Process improvement involves process analysis, standardisation, measurement and change
- Process models include descriptions of tasks, activities, roles, exceptions, communications, deliverables and other processes
- Measurement should be used to answer specific questions about the software process used
- The three types of process metrics, which can be collected, are time metrics, resource utilisation metrics and event metrics
- The SEI model classifies software processes as initial, repeatable, defined, managed and optimising. It identifies key processes, which should be used at each of these levels
- The SEI model is appropriate for large systems developed by large teams of engineers. It cannot be applied without modification in other situations
- Processes can be classified as informal, managed, methodical and improving. This classification can be used to identify process tool support

Activity

Under what circumstances is product quality likely to be determined by the quality of the development team? Give examples of the types of software product that are particularly dependent on individual talent and ability.

Activity

Describe three types of software process metric that may be collected as par of a process improvement process. Give one example of each type of metric.

Activity

Give two advantages and two disadvantages of the approach to process assessment and improvement which is embodied in the SEI process maturity model.

Activity

Suggest two application domains where the SEI capability model is unlikely to be appropriate. Give reasons why this is the case.

Activity

Consider the type of software process used in your organization. How many of the key process areas identified in the SEI model are used? How would this model classify your level of process maturity?

Activity

Suggest three specialized software tools which might be developed to support a process improvement programme in an organization

LESSON 36:
LEGACY SYSTEMS

Older Software Systems That Remain Vital to an Organisation

Objectives

- To explain what is meant by a legacy system and why these systems are important
- To introduce common legacy system structures
- To briefly describe function-oriented design
- To explain how the value of legacy systems can be assessed

Topics Covered

- Legacy system structures
- Legacy system design
- Legacy system assessment

Legacy Systems

- Software systems that are developed specially for an organisation have a long lifetime
- Many software systems that are still in use were developed many years ago using technologies that are now obsolete
- These systems are still business critical that is, they are essential for the normal functioning of the business
- They have been given the name legacy systems

Legacy System Replacement

- There is a significant business risk in simply scrapping a legacy system and replacing it with a system that has been developed using modern technology
- Legacy systems rarely have a complete specification. During their lifetime they have undergone major changes, which may not have been documented
- Business processes are reliant on the legacy system
- The system may embed business rules that are not formally documented elsewhere
- New software development is risky and may not be successful

Legacy System Change

- Systems must change in order to remain useful
- However, changing legacy systems is often expensive
- Different parts implemented by different teams so no consistent programming style
- The system may use an obsolete programming language
- The system documentation is often out-of-date
- The system structure may be corrupted by many years of maintenance
- Techniques to save space or increase speed at the expense of understandability may have been used
- File structures used may be incompatible

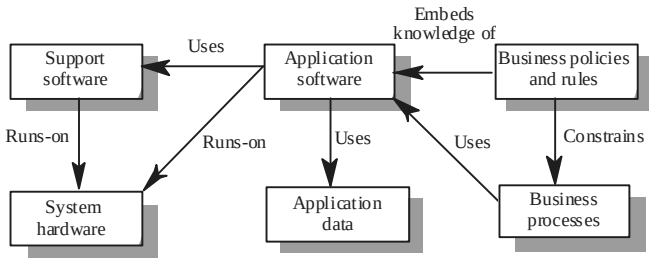
The Legacy Dilemma

- It is expensive and risky to replace the legacy system
- It is expensive to maintain the legacy system
- Businesses must weigh up the costs and risks and may choose to extend the system lifetime using techniques such as re-engineering.

Legacy System Structures

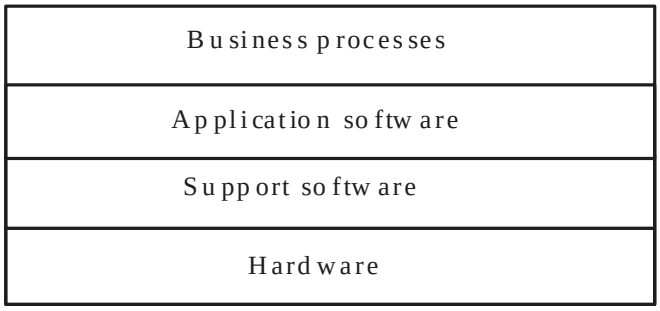
- Legacy systems can be considered to be socio-technical systems and not simply software systems
- System hardware : May be mainframe hardware
- Support software : Operating systems and utilities
- Application software : Several different programs
- Application data : Data used by these programs that is often critical business information
- Business processes : The processes that support a business objective and which rely on the legacy software and hardware
- Business policies and rules : Constraints on business operations

Legacy System Components



Layered Model

Socio-technical system

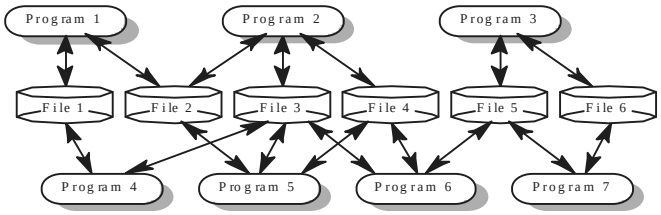


System Change

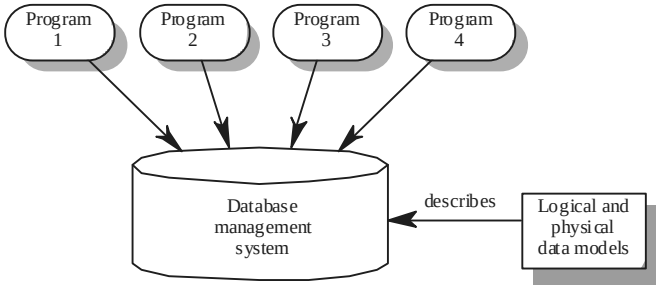
- In principle, it should be possible to replace a layer in the system leaving the other layers unchanged
- In practice, this is usually impossible

- Changing one layer introduces new facilities and higher-level layers must then change to make use of these
- Changing the software may slow it down so hardware changes are then required
- It is often impossible to maintain hardware interfaces because of the wide gap between mainframes and client-server systems

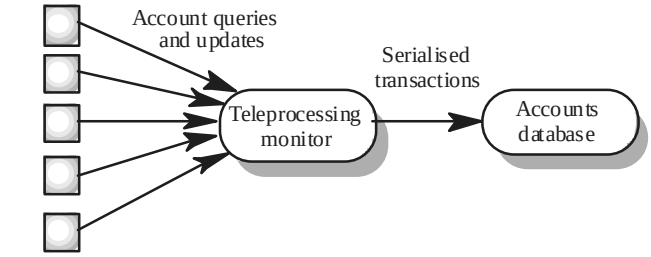
Legacy Application System



Database-centred System



Transaction Processing



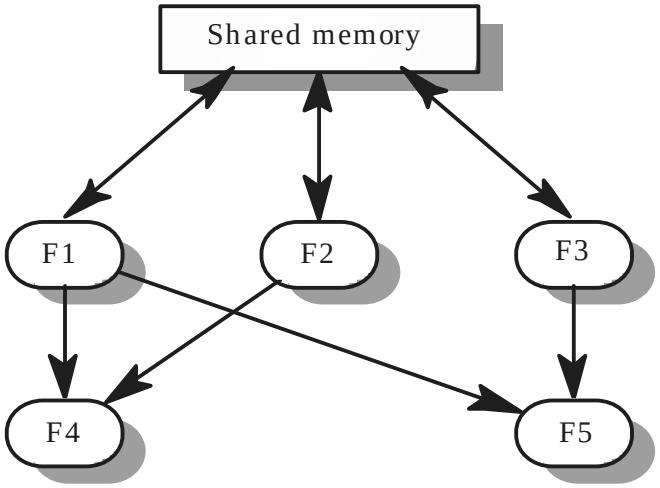
Legacy Data

- The system may be file-based with incompatible files. The change required may be to move to a database-management system
- In legacy systems that use a DBMS (the database management system) may be obsolete and incompatible with other DBMSs used by the business
- The teleprocessing monitor may be designed for a particular DB and mainframe. Changing to a new DB may require a new TP monitor

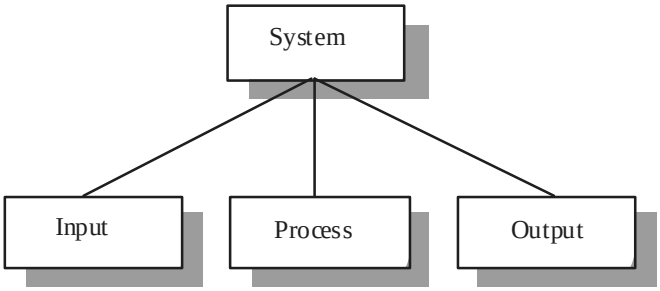
Legacy System Design

- Most legacy systems were designed before object-oriented development was used
- Rather than being organised as a set of interacting objects, these systems have been designed using a function-oriented design strategy
- Several methods and CASE tools are available to support function-oriented design and the approach is still used for many business applications

A Function-oriented View of Design



Input-process-output Model



Input-process-output

- Input components read and validate data from a terminal or file
- Processing components carry out some transformations on that data
- Output components format and print the results of the computation
- Input, process and output can all be represented as functions with data 'flowing' between them

Functional Design Process

- Data-flow design

Model the data processing in the system using data-flow diagrams

- Structural decomposition

Model how functions are decomposed to sub-functions using graphical structure charts that reflect the input/process/output structure

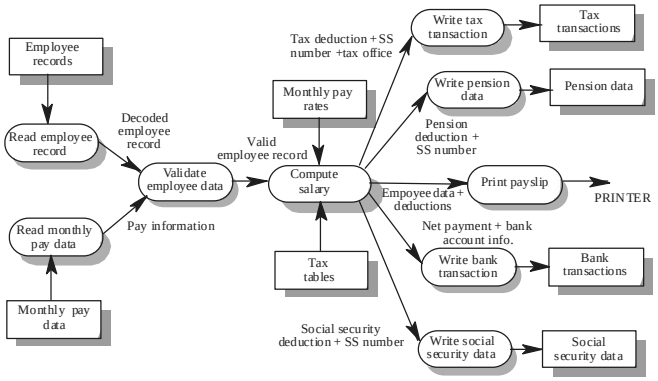
- Detailed design

The functions in the design and their interfaces are described in detail. These may be recorded in a data dictionary and the design expressed using a PDL

Data Flow Diagrams

- Show how an input data item is functionally transformed by a system into an output data item
- Are an integral part of many design methods and are supported by many CASE systems
- May be translated into either a sequential or parallel design. In a sequential design, processing elements are functions or procedures; in a parallel design, processing elements are tasks or processes

Payroll System DFD



Payroll Batch Processing

- The functions on the left of the DFD are input functions

Read employee record, Read monthly pay data, Validate employee data

- The central function : Compute salary : carries out the processing
- The functions to the right are output functions

Write tax transaction, Write pension data, Print payslip, Write bank transaction, and Write social security data

Transaction Processing

- A bank ATM system is an example of a transaction processing system
- Transactions are stateless in that they do not rely on the result of previous transactions. Therefore, a functional approach is a natural way to implement transaction processing

Design Description of an ATM

```
INPUT

loop
    repeat
        Print_input_message (" Welcome - Please enter your card") ;
    until Card_input ;

    Account_number := Read_card ;
    Get_account_details (PIN,Account_balance, Cash_available) ;
```

```
PROCESS

    if Invalid_card (PIN) then
        Retain_card ;
        Print ("Card retained - please contact your bank") ;
    else
    repeat
        Print_operation_select_message ;
        Button := Get_button ;
        case Get_button is
            when Cash_only =>
                Dispense_cash (Cash_available, Amount_dispensed) ;
            when Print_balance =>
                Print_customer_balance (Account_balance) ;
            when Statement =>
                Order_statement (Account_number) ;
            when Check_book =>
                Order_checkbook (Account_number) ;
        end case ;
        Print ("Press CONTINUE for more services or STOP to finish");
        Button := Get_button ;
    until Button = STOP ;
```

```
OUTPUT

    Eject_card ;
    Print ("Please take your card ) ;
    Update_account_information (Account_number Amount_dispensed) ;

end loop ;
```

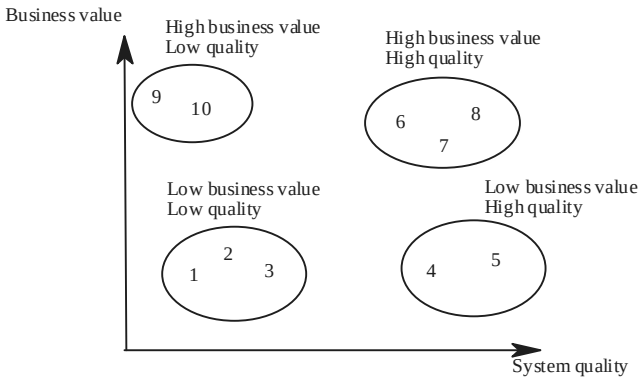
Using Function-oriented Design

- For some classes of system, such as some transaction processing systems, a function-oriented approach may be a better approach to design than an object-oriented approach
- Companies may have invested in CASE tools and methods for function-oriented design and may not wish to incur the costs and risks of moving to an object-oriented approach

Legacy System Assessment

- Organisations that rely on legacy systems must choose a strategy for evolving these systems
- Scrap the system completely and modify business processes so that it is no longer required
- Continue maintaining the system
- Transform the system by re-engineering to improve its maintainability
- Replace the system with a new system
- The strategy chosen should depend on the system quality and its business value

System Quality and Business Value



Legacy System Categories

- Low quality, low business value : These systems should be scrapped
- Low-quality, high-business value : These make an important business contribution but are expensive to maintain. Should be re-engineered or replaced if a suitable system is available
- High-quality, low-business value : Replace with COTS, scrap completely or maintain
- High-quality, high business value : Continue in operation using normal system maintenance

Business Value Assessment

- Assessment should take different viewpoints into account

System end-users

Business customers

Line managers

IT managers

Senior managers

- Interview different stakeholders and collate results

System Quality Assessment

- Business process assessment : How well does the business process support the current goals of the business?
- Environment assessment : How effective is the system's environment and how expensive is it to maintain?
- Application assessment : What is the quality of the application software system?

Business Process Assessment

- Use a viewpoint-oriented approach and seek answers from system stakeholders
- Is there a defined process model and is it followed?
- Do different parts of the organisation use different processes for the same function?
- How has the process been adapted?
- What are the relationships with other business processes and are these necessary?
- Is the process effectively supported by the legacy application software?

Environment Assessment

Factor	Questions
Supplier stability	Is the supplier is still in existence? Is the supplier financially stable and likely to continue in existence? If the supplier is no longer in business, are the systems maintained by someone else?
Failure rate	Does the hardware have a high rate of reported failures? Does the support software crash and force system restarts?
Age	How old is the hardware and software? The older the hardware and support software, the more obsolete it will be. It may still function correctly but there could be significant economic and business benefits to moving to more modern systems.
Performance	Is the performance of the system adequate? Do performance problems have a significant effect on system users?
Support requirements	What local support is required by the hardware and software? If there are high costs associated with this support, it may be worth considering system replacement.
Maintenance costs	What are the costs of hardware maintenance and support software licences? Older hardware may have higher maintenance costs than modern systems. Support software may have high annual licensing costs.
Interoperability	Are there problems interfacing the system to other systems? Can compilers etc. be used with current versions of the operating system? Is hardware emulation required?

Application Assessment

Factor	Questions
Understandability	How difficult is it to understand the source code of the current system? How complex are the control structures which are used? Do variables have meaningful names that reflect their function?
Documentation	What system documentation is available? Is the documentation complete, consistent and up-to-date?
Data	Is there an explicit data model for the system? To what extent is data duplicated in different files? Is the data used by the system up-to-date and consistent?
Performance	Is the performance of the application adequate? Do performance problems have a significant effect on system users?
Programming language	Are modern compilers available for the programming language used to develop the system? Is the programming language still used for new system development?
Configuration management	Are all versions of all parts of the system managed by a configuration management system? Is there an explicit description of the versions of components that are used in the current system?
Test data	Does test data for the system exist? Is there a record of regression tests carried out when new features have been added to the system?
Personnel skills	Are there people available who have the skills to maintain the application? Are there only a limited number of people who understand the system?

System Measurement

- You may collect quantitative data to make an assessment of the quality of the application system
- The number of system change requests
- The number of different user interfaces used by the system
- The volume of data used by the system

Key Points

- A legacy system is an old system that still provides essential business services
- Legacy systems are not just application software but also include business processes, support software and hardware
- Most legacy systems are made up of several different programs and shared data
- A function-oriented approach has been used in the design of most legacy systems
- The structure of legacy business systems normally follows an input-process-output model
- The business value of a system and its quality should be used to choose an evolution strategy
- The business value reflects the system's effectiveness in supporting business goals
- System quality depends on business processes, the system's environment and the application software

Activity

Explain why legacy systems may be critical to the operation of a business.

Activity

What difficulties are likely to arise when different components of a legacy system are implemented in different programming languages?

Activity

Suggest three reasons why software systems become more difficult to understand when different people are involved in changing these systems.

Activity

Why is it necessary to use a teleprocessing monitor when requests to update data in a system come form a number of different terminals? How do modern client-server systems reduce the load on the teleprocessing monitor?

Activity

Most legacy systems use a function oriented approach to design. Explain why this approach to design may be more appropriate for these systems than an object oriented design strategy.

Activity

Under what circumstances might an organization decide to scrap a system when the system assessment suggests that it is of high quality and high business value?

Activity

Suggest 10 questions that might be put to end users of a system when carrying out a business process assessment.

Activity

Explain why problems with support software might mean that an organization has to replaces its legacy systems.

Activity

The management of an organization has asked you to carry out a system assessment and has suggested to you that they would like the results of that assessment to show that the system is obsolete and that it should be replaced by a new system. This will mean that a number of system maintainers are made redundant. Your assessment actually shoes that the system is well maintained and is of high quality and high business value. How would you report these results to the management of the organization?

Notes:

LESSON 37:
SOFTWARE CHANGE

Managing the Processes of Software System Change

Objectives

- To explain different strategies for changing software systems

Software maintenance

Architectural evolution

Software re-engineering

- To explain the principles of software maintenance
- To describe the transformation of legacy systems from centralised to distributed architectures

Topics Covered

- Program evolution dynamics
- Software maintenance
- Architectural evolution

Software Change

- Software change is inevitable

New requirements emerge when the software is used

The business environment changes

Errors must be repaired

New equipment must be accommodated

The performance or reliability may have to be improved

- A key problem for organisations is implementing and managing change to their legacy systems

Software Change Strategies

- Software maintenance

Changes are made in response to changed requirements but the fundamental software structure is stable

- Architectural transformation

The architecture of the system is modified generally from a centralised architecture to a distributed architecture

- Software re-engineering

No new functionality is added to the system but it is restructured and reorganised to facilitate future changes

- These strategies may be applied separately or together

Program Evolution Dynamics

- Program evolution dynamics is the study of the processes of system change
- After major empirical study, Lehman and Belady proposed that there were a number of 'laws', which applied to all systems as they evolved
- There are sensible observations rather than laws. They are applicable to large systems developed by large organisations. Perhaps less applicable in other cases

Lehman's laws

Law	Description
Continuing change	A program that is used in a real-world environment necessarily must change or become progressively less useful in that environment.
Increasing complexity	As an evolving program changes, its structure tends to become more complex. Extra resources must be devoted to preserving and simplifying the structure.
Large program evolution	Program evolution is a self-regulating process. System attributes such as size, time between releases and the number of reported errors are approximately invariant for each system release.
Organisational stability	Over a program's lifetime, its rate of development is approximately constant and independent of the resources devoted to system development.
Conservation of familiarity	Over the lifetime of a system, the incremental change in each release is approximately constant.

Applicability of Lehman's Laws

- This has not yet been established
- They are generally applicable to large, tailored systems developed by large organisations
- It is not clear how they should be modified for

Shrink-wrapped software products

Systems that incorporate a significant number of COTS components

Small organisations

Medium-sized systems

Software Maintenance

- Modifying a program after it has been put into use
- Maintenance does not normally involve major changes to the system's architecture
- Changes are implemented by modifying existing components and adding new components to the system

Maintenance is Inevitable

- The system requirements are likely to change while the system is being developed because the environment is changing. Therefore a delivered system won't meet its requirements!
- Systems are tightly coupled with their environment. When a system is installed in an environment it changes that environment and therefore changes the system requirements.
- Systems MUST be maintained therefore if they are to remain useful in an environment

Types of Maintenance

- Maintenance to repair software faults

Changing a system to correct deficiencies in the way meets its requirements

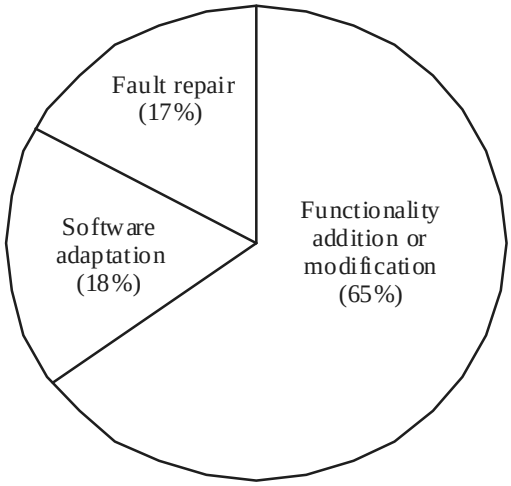
- Maintenance to adapt software to a different operating environment

Changing a system so that it operates in a different environment (computer, OS, etc.) from its initial implementation

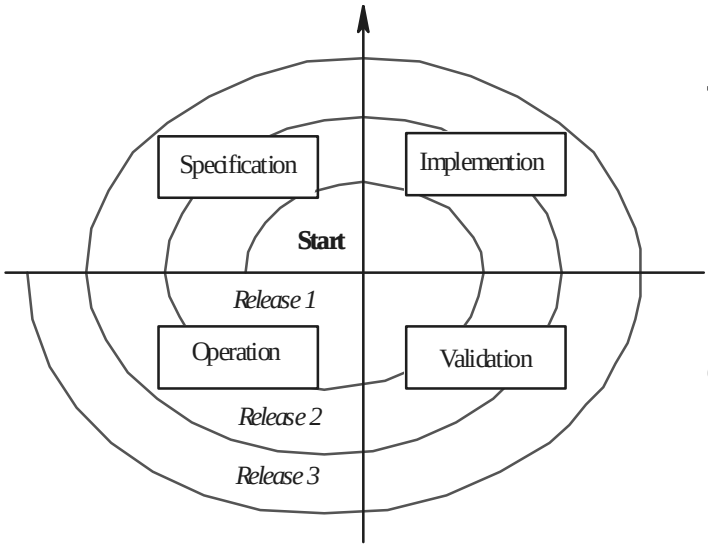
- Maintenance to add to or modify the system's functionality

Modifying the system to satisfy new requirements

Distribution of Maintenance Effort



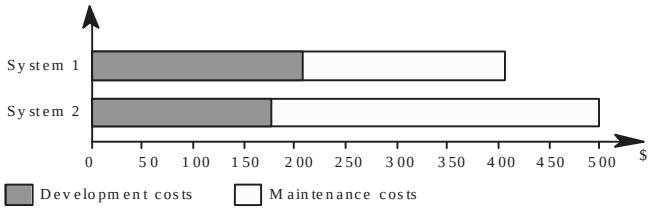
Spiral Maintenance Model



Maintenance Costs

- Usually greater than development costs (2* to 100* depending on the application)
- Affected by both technical and non-technical factors
- Increases as software is maintained. Maintenance corrupts the software structure so makes further maintenance more difficult.
- Ageing software can have high support costs (e.g. old languages, compilers etc.)

Development/Maintenance Costs



Maintenance Cost Factors

- Team stability

Maintenance costs are reduced if the same staff are involved with them for some time

- Contractual responsibility

The developers of a system may have no contractual responsibility for maintenance so there is no incentive to design for future change

- Staff skills

Maintenance staff are often inexperienced and have limited domain knowledge

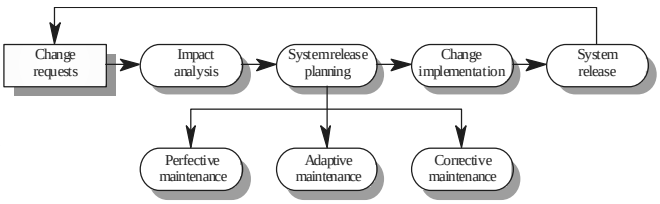
- Program age and structure

As programs age, their structure is degraded and they become harder to understand and change

Evolutionary Software

- Rather than think of separate development and maintenance phases, evolutionary software is software that is designed so that it can continuously evolve throughout its lifetime

The Maintenance Process



Change Requests

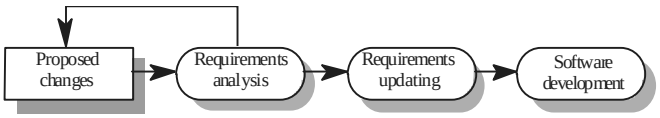
- Change requests are requests for system changes from users, customers or management
- In principle, all change requests should be carefully analysed as part of the maintenance process and then implemented
- In practice, some change requests must be implemented urgently

Fault repair

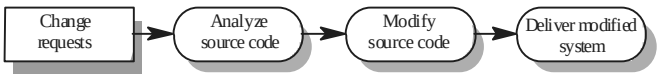
Changes to the system's environment

Urgently required business changes

Change Implementation



Emergency Repair



Maintenance Prediction

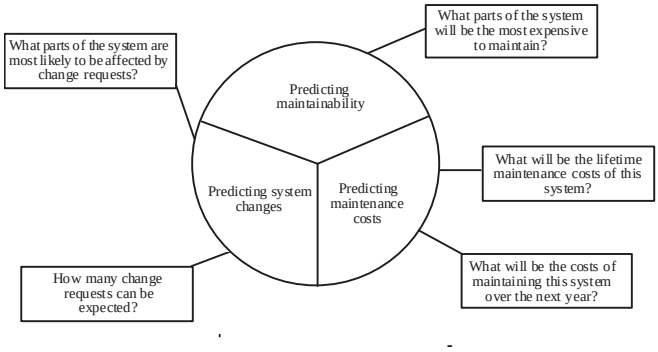
- Maintenance prediction is concerned with assessing which parts of the system may cause problems and have high maintenance costs

Change acceptance depends on the maintainability of the components affected by the change

Implementing changes degrades the system and reduces its maintainability

Maintenance costs depend on the number of changes and costs of change depend on maintainability

Maintenance Prediction


What parts of the system are most likely to be affected by change requests?
What parts of the system will be the most expensive to maintain?
Predicting maintainability
What will be the lifetime maintenance costs of this system?
Predicting system changes
Predicting maintenance costs
How many change requests can be expected?
What will be the costs of maintaining this system over the next year?

Change Prediction

- Predicting the number of changes requires and understanding of the relationships between a system and its environment
- Tightly coupled systems require changes whenever the environment is changed
- Factors influencing this relationship are

Number and complexity of system interfaces

Number of inherently volatile system requirements

The business processes where the system is used

Complexity Metrics

- Predictions of maintainability can be made by assessing the complexity of system components
- Studies have shown that most maintenance effort is spent on a relatively small number of system components
- Complexity depends on

Complexity of control structures

Complexity of data structures

Procedure and module size

Process Metrics

- Process measurements may be used to assess maintainability

Number of requests for corrective maintenance

Average time required for impact analysis

Average time taken to implement a change request

Number of outstanding change requests

- If any or all of these is increasing, this may indicate a decline in maintainability

Architectural Evolution

- There is a need to convert many legacy systems from a centralised architecture to client-server architecture
- Change drivers

Hardware costs : Servers are cheaper than mainframes

User interface expectations : Users expect graphical user interfaces

Distributed access to systems : Users wish to access the system from different, geographically separated, computers

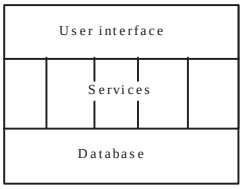
Distribution Factors

Factor	Description
Business importance	Returns on the investment of distributing a legacy system depend on its importance to the business and how long it will remain important. If distribution provides more efficient support for stable business processes then it is more likely to be a cost-effective evolution strategy.
System age	The older the system the more difficult it will be to modify its architecture because previous changes will have degraded the structure of the system.
System structure	The more modular the system, the easier it will be to change the architecture. If the application logic, the data management and the user interface of the system are closely intertwined, it will be difficult to separate functions for migration.
Hardware procurement policies	Application distribution may be necessary if there is company policy to replace expensive mainframe computers with cheaper servers. .

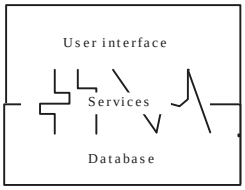
Legacy System Structure

- Ideally, for distribution, there should be a clear separation between the user interface, the system services and the system data management
- In practice, these are usually intermingled in older legacy systems

Legacy System Structures

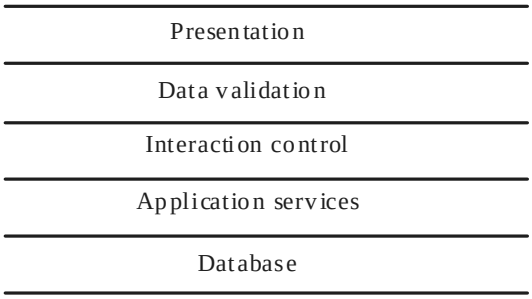


Ideal model for distribution

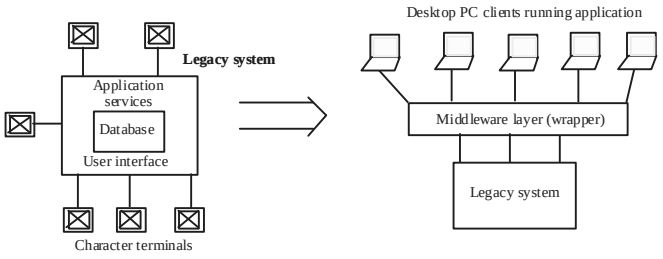


Real legacy systems

Layered Distribution Model



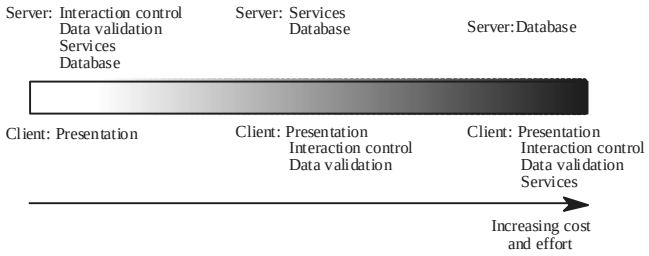
Legacy System Distribution



Distribution Options

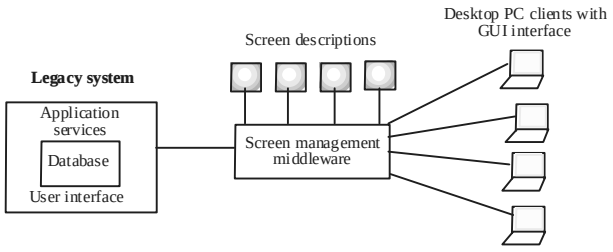
- The more that is distributed from the server to the client, the higher the costs of architectural evolution
- The simplest distribution model is UI distribution where only the user interface is implemented on the server
- The most complex option is where the server simply provides data management and application services are implemented on the client

Distribution Option Spectrum



User Interface Distribution

- UI distribution takes advantage of the local processing power on PCs to implement a graphical user interface
- Where there is a clear separation between the UI and the application then the legacy system can be modified to distribute the UI
- Otherwise, screen management middleware can translate text interfaces to graphical interfaces



UI Migration Strategies

Strategy	Advantages	Disadvantages
Implementation using the window management system	Access to all UI functions so no real restrictions on UI design Better UI performance	Platform dependent May be more difficult to achieve interface consistency
Implementation using a web browser	Platform independent Lower training costs due to user familiarity with the WWW Easier to achieve interface consistency	Potentially poorer UI performance Interface design is constrained by the facilities provided by web browsers

Key Points

- Software change strategies include software maintenance, architectural evolution and software re-engineering
- Lehman's Laws are invariant relationships that affect the evolution of a software system
- Maintenance types are

Maintenance for repair

Maintenance for a new operating environment

Maintenance to implement new requirements

- The costs of software change usually exceed the costs of software development
- Factors influencing maintenance costs include staff stability, the nature of the development contract, skill shortages and degraded system structure
- Architectural evolution is concerned with evolving centralised to distributed architectures
- A distributed user interface can be supported using screen management middleware

Activity

Explain why a software system which is used in a real world environment must change or become progressively less useful.

Activity

Explain the difficulties of measuring program maintainability. Suggest why you should use several different complexity metrics when trying to assess the maintainability of a program.

Activity

As a software project manager in a company that specializes in the development of software for the offshore oil industry, you have been given the task of discovering those factors which affect the maintainability of the particular systems which are developed by your company. Suggest how you might set up a programme to analyze the maintenance process to discover appropriate maintainability metrics for your company.

Activity

Two major international banks with different customer information databases merge and decide that they need to provide access to all customer information form all bank branches. Giving reasons for your answer, suggest the most appropriate strategy for providing access to these systems and briefly discuss how the solution might be implemented.

Activity

Do software engineers have a professional responsibility to produce maintainable code even if this is not explicitly requested by their employer?

LESSON 38:
SOFTWARE RE-ENGINEERING

Reorganising and Modifying Existing Software Systems to Make them More Maintainable

Objectives

- To explain why software re-engineering is a cost-effective option for system evolution
- To describe the activities involved in the software re-engineering process
- To distinguish between software and data re-engineering and to explain the problems of data re-engineering

Topics Covered

- Source code translation
- Reverse engineering
- Program structure improvement
- Program modularisation
- Data re-engineering

System Re-engineering

- Re-structuring or re-writing part or all of a legacy system without changing its functionality
- Applicable where some but not all sub-systems of a larger system require frequent maintenance
- Re-engineering involves adding effort to make them easier to maintain. The system may be re-structured and re-documented

When to Re-engineer

- When system changes are mostly confined to part of the system then re-engineer that part
- When hardware or software support becomes obsolete
- When tools to support re-structuring are available

Re-engineering Advantages

- Reduced risk

There is a high risk in new software development. There may be development problems, staffing problems and specification problems

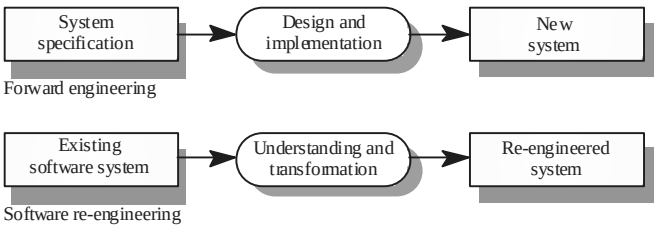
- Reduced cost

The cost of re-engineering is often significantly less than the costs of developing new software

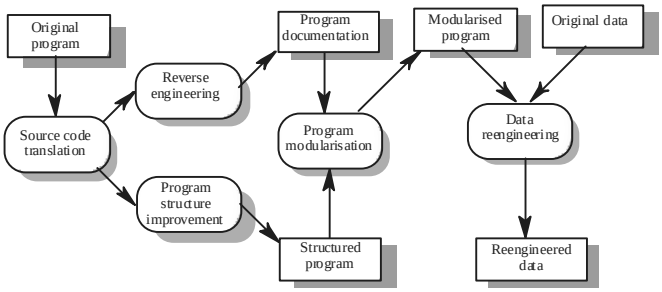
Business Process Re-engineering

- Concerned with re-designing business processes to make them more responsive and more efficient
- Often reliant on the introduction of new computer systems to support the revised processes
- May force software re-engineering as the legacy systems are designed to support existing processes

Forward Engineering And Re-engineering



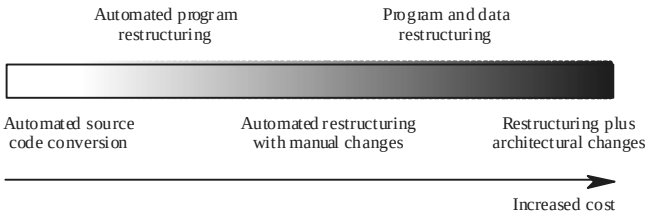
The Re-engineering Process



Re-engineering Cost Factors

- The quality of the software to be re-engineered
- The tool support available for re-engineering
- The extent of the data conversion, which is required
- The availability of expert staff for re-engineering

Re-engineering Approaches



Source Code Translation

- Involves converting the code from one language (or language version) to another e.g. FORTRAN to C
- May be necessary because of:

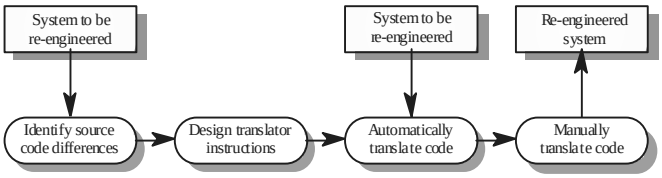
Hardware platform update

Staff skill shortages

Organisational policy changes

- Only realistic if an automatic translator is available

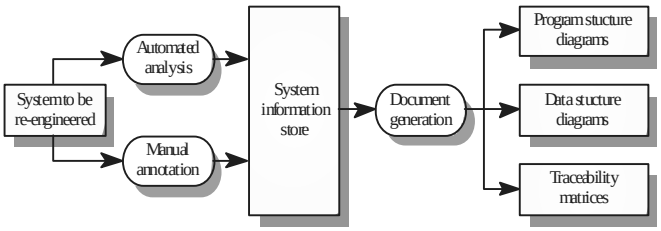
The Program Translation Process



Reverse Engineering

- Analysing software with a view to understanding its design and specification
- May be part of a re-engineering process but may also be used to re-specify a system for re-implementation
- Builds a program data base and generates information from this
- Program understanding tools (browsers, cross-reference generators, etc.) may be used in this process

The Reverse Engineering Process



- Reverse engineering often precedes re-engineering but is sometimes worthwhile in its own right

The design and specification of a system may be reverse engineered so that they can be an input to the requirements specification process for the system's replacement

The design and specification may be reverse engineered to support program maintenance

Program Structure Improvement

- Maintenance tends to corrupt the structure of a program. It becomes harder and harder to understand
- The program may be automatically restructured to remove unconditional branches
- Conditions may be simplified to make them more readable

Condition Simplification

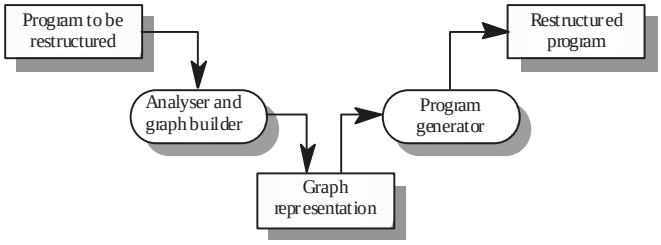
Complex condition

```
if not (A > B and (C < D or not (E > F)))...
```

Simplified condition

```
if (A <= B and (C>= D or E > F)...
```

Automatic Program Restructuring



Restructuring Problems

- Problems with re-structuring are:

Loss of comments

Loss of documentation

Heavy computational demands

- Restructuring doesn't help with poor modularisation where related components are dispersed throughout the code
- The understandability of data-driven programs may not be improved by re-structuring

Program Modularisation

- The process of re-organising a program so that related program parts are collected together in a single module
- Usually a manual process that is carried out by program inspection and re-organisation

Module Types

- Data abstractions :A bstract data types where data structures and associated operations are grouped
- Hardware modules : All functions required to interface with a hardware unit
- Functional modules : Modules containing functions that carry out closely related tasks
- Process support modules : Modules where the functions support a business process or process fragment

Recovering Data Abstractions

- Many legacy systems use shared tables and global data to save memory space
- Causes problems because changes have a wide impact in the system
- Shared global data may be converted to objects or ADTs

Analyse common data areas to identify logical abstractions

Create an ADT or object for these abstractions

Use a browser to find all data references and replace with reference to the data abstraction

Data Abstraction Recovery

- Analyse common data areas to identify logical abstractions
- Create an abstract data type or object class for each of these abstractions
- Provide functions to access and update each field of the data abstraction
- Use a program browser to find calls to these data abstractions and replace these with the new defined functions

Data Re-engineering

- Involves analysing and reorganising the data structures (and sometimes the data values) in a program
- May be part of the process of migrating from a file-based system to a DBMS-based system or changing from one DBMS to another
- Objective is to create a managed data environment

Approaches to Data Re-engineering

Approach	Description
Data cleanup	The data records and values are analysed to improve their quality. Duplicates are removed, redundant information is deleted and a consistent format applied to all records. This should not normally require any associated program changes.
Data extension	In this case, the data and associated programs are re-engineered to remove limits on the data processing. This may require changes to programs to increase field lengths, modify upper limits on the tables, etc. The data itself may then have to be rewritten and cleaned up to reflect the program changes.
Data migration	In this case, data is moved into the control of a modern database management system. The data may be stored in separate files or may be managed by an older type of DBMS.

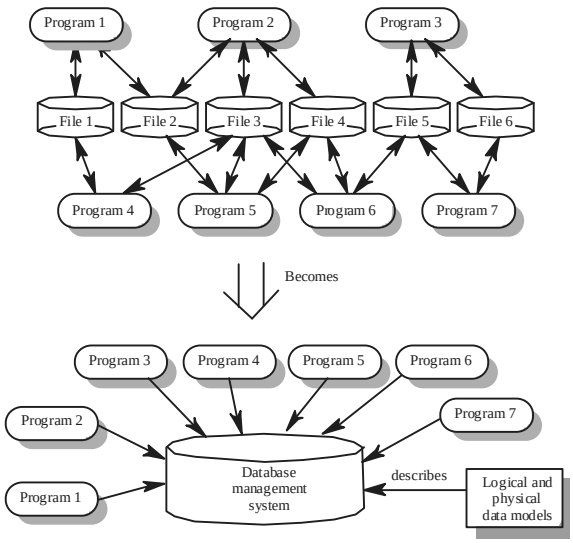
Data Problems

- End-users want data on their desktop machines rather than in a file system. They need to be able to download this data from a DBMS
- Systems may have to process much more data than was originally intended by their designers
- Redundant data may be stored in different formats in different places in the system

Data Value Inconsistencies

Data inconsistency	Description
Inconsistent default values	Different programs assign different default values to the same logical data items. This causes problems for programs other than those that created the data. The problem is compounded when missing values are assigned a default value that is valid. The missing data cannot then be discovered.
Inconsistent units	The same information is represented in different units in different programs. For example, in the US or the UK, weight data may be represented in pounds in older programs but in kilograms in more recent systems. A major problem of this type has arisen in Europe with the introduction of a single European currency. Legacy systems have been written to deal with national currency units and data has to be converted to euros.
Inconsistent validation rules	Different programs apply different data validation rules. Data written by one program may be rejected by another. This is a particular problem for archival data which may not have been updated in line with changes to data validation rules.
Inconsistent representation semantics	Programs assume some meaning in the way items are represented. For example, some programs may assume that upper-case text means an address. Programs may use different conventions and may therefore reject data which is semantically valid.
Inconsistent handling of negative values	Some programs reject negative values for entities which must always be positive. Others, however, may accept these as negative values or fail to recognise them as negative and convert them to a positive value.

Data Migration



- Data naming problems

Names may be hard to understand. The same data may have different names in different programs

- Field length problems

The same item may be assigned different lengths in different programs

- Record organisation problems

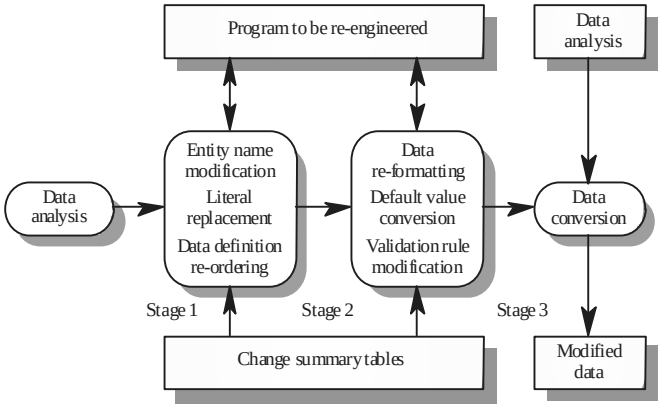
Records representing the same entity may be organised differently in different programs

- Hard-coded literals
- No data dictionary

Data Conversion

- Data re-engineering may involve changing the data structure organisation without changing the data values
- Data value conversion is very expensive. Special-purpose programs have to be written to carry out the conversion

The Data Re-engineering Process



Key Points

- The objective of re-engineering is to improve the system structure to make it easier to understand and maintain
- The re-engineering process involves source code translation, reverse engineering, program structure improvement, program modularisation and data re-engineering
- Source code translation is the automatic conversion of program in one language to another
- Reverse engineering is the process of deriving the system design and specification from its source code
- Program structure improvement replaces unstructured control constructs with while loops and simple conditionals
- Program modularisation involves reorganisation to group related items
- Data re-engineering may be necessary because of inconsistent data management

Activity

Under what circumstances do you think that software should scrapped and rewritten rather than re-engineered?

Activity

Write a set of guidelines that may be used to help find modules in an unstructured program.

Activity

What problems might arise when converting data form one type of database management system to another (e.g. hierarchical to relational or relational to object –oriented?

Activity

Explain why it is impossible to recover a system specification be automatically analyzing system source code.

Activity

Using examples, describe the problems with data degradation which may have to be tackled during the process of data cleanup.

Activity

The year 2000 problem where dates were represented as two digits posed a major program maintenance problem for many organizations. What were the implications of this problem for data re-engineering?

Activity

A company routinely places contractual conditions on freelance working on re-engineering their applications which prevents them from taking on contracts with similar companies. The reason for this is that re-engineering inevitably reveals business information. Is this a reasonable position for a company to take given that they have no obligations to contractors after their contract has finished?

LESSON 39 AND 40:
CONFIGURATION MANAGEMENT

Managing The Products of System Change

Objectives

- To explain the importance of software configuration management (CM)
- To describe key CM activities namely CM planning, change management, version management and system building
- To discuss the use of CASE tools to support configuration management processes

Topics Covered

- Configuration management planning
- Change management
- Version and release management
- System building
- CASE tools for configuration management

Configuration Management

- New versions of software systems are created as they change

For different machines/OS

Offering different functionality

Tailored for particular user requirements

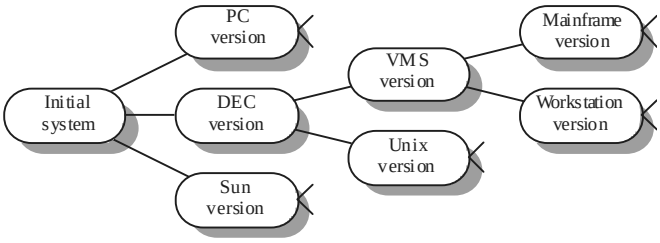
- Configuration management is concerned with managing evolving software systems

System change is a team activity

CM aims to control the costs and effort involved in making changes to a system

- Involves the development and application of procedures and standards to manage an evolving software product
- May be seen as part of a more general quality management process
- When released to CM, software systems are sometimes called baselines, as they are a starting point for further development

System Families



CM Standards

- CM should always be based on a set of standards, which are applied within an organisation
- Standards should define how items are identified; how changes are controlled and how new versions are managed
- Standards may be based on external CM standards (e.g. IEEE standard for CM)
- Existing standards are based on a waterfall process model - new standards are needed for evolutionary development

Concurrent Development And Testing

- A time for delivery of system components is agreed
- A new version of a system is built from these components by compiling and linking them
- This new version is delivered for testing using pre-defined tests
- Faults that are discovered during testing are documented and returned to the system developers

Daily System Building

- It is easier to find problems that stem from component interactions early in the process
- This encourages thorough unit testing : Developers are under pressure not to 'break the build'
- A stringent change management process is required to keep track of problems that have been discovered and repaired

Configuration Management Planning

- All products of the software process may have to be managed

Specifications

Designs

Programs

Test data

User manuals

- Thousands of separate documents are generated for a large software system

CM Planning

- Starts during the early phases of the project
- Must define the documents or document classes, which are to be managed (Formal documents)
- Documents which might be required for future system maintenance should be identified and specified as managed documents

The CM Plan

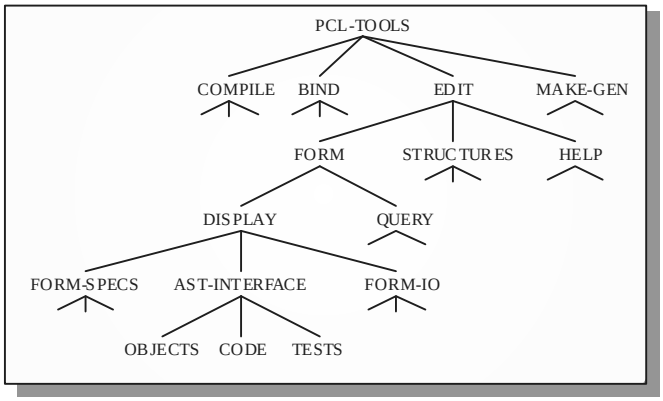
- Defines the types of documents to be managed and a document naming scheme
- Defines who takes responsibility for the CM procedures and creation of baselines
- Defines policies for change control and version management
- Defines the CM records which must be maintained

- Describes the tools, which should be used to assist the CM process and any limitations on their use
- Defines the process of tool use
- Defines the CM database used to record configuration information
- May include information such as the CM of external software, process auditing, etc.

Configuration Item Identification

- Large projects typically produce thousands of documents, which must be uniquely identified
- Some of these documents must be maintained for the lifetime of the software
- Document naming scheme should be defined so that related documents have related names.
- A hierarchical scheme with multi-level names is probably the most flexible approach

Configuration Hierarchy



The Configuration Database

- All CM information should be maintained in a configuration database
- This should allow queries about configurations to be answered

Who has a particular system version?

What platform is required for a particular version?

What versions are affected by a change to component X?

How many reported faults in version T?

- The CM database should preferably be linked to the software being managed

Cm Database Implementation

- May be part of an integrated environment to support software development. The CM database and the managed documents are all maintained on the same system
- CASE tools may be integrated with this so that there is a close relationship between the CASE tools and the CM tools
- More commonly, the CM database is maintained separately as this is cheaper and more flexible

Change Management

- Software systems are subject to continual change requests

From users

From developers

From market forces

- Change management is concerned with keeping managing of these changes and ensuring that they are implemented in the most cost-effective way

The Change Management Process

```
Request change by completing a change request form
Analyze change request
if change is valid  then
    Assess how change might be implemented
    Assess change cost
   Submit request to change control board
   if change is accepted  then
      repeat
        make changes to software
        submit changed software for quality approval
     until software quality is adequate
    create new system version
 else
    reject change request
else
    reject change request
```

Change Request Form

- Definition of change request form is part of the CM planning process
- Records change required, suggestor of change, reason why change was suggested and urgency of change (from requestor of the change)
- Records change evaluation, impact analysis, change cost and recommendations (System maintenance staff)

Change Request Form

Project: Proteus/PCL-Tools **Number:** 23/94
Change requester: I. Sommerville **Date:** 1/12/98
Requested change: When a component is selected from the structure, display the name of the file where it is stored.

Change analyser: G. Dean **Analysis date:** 10/12/98
Components affected: Display-Icon.Select, Display-Icon.Display

Associated components: FileTable

Change assessment: Relatively simple to implement as a file name table is available. Requires the design and implementation of a display field. No changes to associated components are required.

Change priority: Low
Change implementation:
Estimated effort: 0.5 days
Date to CCB: 15/12/98 **CCB decision date:** 1/2/99
CCB decision: Accept change. Change to be implemented in Release 2.1.
Change implementor: **Date of change:**
Date submitted to QA: **QA decision:**
Date submitted to CM:
Comments

Change Tracking Tools

- A major problem in change management is tracking change status

- Change tracking tools keep track the status of each change request and automatically ensure that change requests are sent to the right people at the right time.
- Integrated with E-mail systems allowing electronic change request distribution

Change Control Board

- Changes should be reviewed by an external group who decide whether or not they are cost-effective from a strategic and organizational viewpoint rather than a technical viewpoint
- Should be independent of project responsible for system. The group is sometimes called a change control board
- May include representatives from client and contractor staff

Derivation History

- Record of changes applied to a document or code component
- Should record, in outline, the change made, the rationale for the change, who made the change and when it was implemented
- May be included as a comment in code. If a standard prologue style is used for the derivation history, tools can process this automatically

Component Header Information

```
// PROTEUS project (ESPRIT 6087)
//
// PCL-TOOLS/EDIT/FORMS/DISPLAY/AST-INTERFACE
//
// Object: PCL-Tool-Desc
// Author: G. Dean
// Creation date: 10th November 1998
//
// © Lancaster University 1998
//
// Modification history
// Version   Modifier  Date       Change      Reason
// 1.0       J. Jones  1/12/1998  Add header  Submitted to CM
// 1.1       G. Dean   9/4/1999   New field   Change req. R07/99
```

Version and Release Management

- Invent identification scheme for system versions
- Plan when new system version is to be produced
- Ensure that version management procedures and tools are properly applied
- Plan and distribute new system releases

Versions/Variants/Releases

- Version : An instance of a system, which is functionally distinct in some way from other system instances
- Variant : An instance of a system, which is functionally identical but non-functionally distinct from other instances of a system
- Release : An instance of a system, which is distributed to users outside of the development team

Version Identification

- Procedures for version identification should define an unambiguous way of identifying component versions
- Three basic techniques for component identification

Version numbering

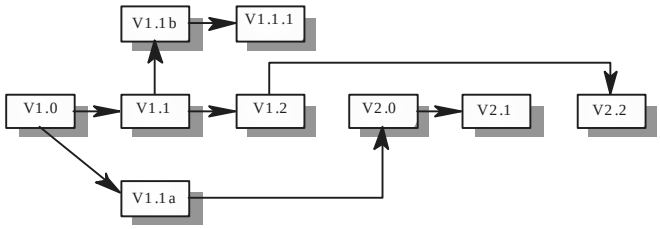
Attribute-based identification

Change-oriented identification

Version Numbering

- Simple naming scheme uses a linear derivation e.g. V1, V1.1, V1.2, V2.1, V2.2 etc.
- Actual derivation structure is a tree or a network rather than a sequence
- Names are not meaningful.
- Hierarchical naming scheme may be better

Version Derivation Structure



Attribute-based Identification

- Attributes can be associated with a version with the combination of attributes identifying that version
- Examples of attributes are Date, Creator, Programming Language, Customer, and Status etc.
- More flexible than an explicit naming scheme for version retrieval; Can cause problems with uniqueness
- Needs an associated name for easy reference

Attribute-based Queries

- An important advantage of attribute-based identification is that it can support queries so that you can find 'the most recent version in Java' etc.

Example

AC3D (language =Java, platform = NT4, date = Jan 1999)

Change-oriented Identification

- Integrates versions and the changes made to create these versions
- Used for systems rather than components
- Each proposed change has a change set that describes changes made to implement that change
- Change sets are applied in sequence so that, in principle, a version of the system that incorporates an arbitrary set of changes may be created

Release Management

- Releases must incorporate changes forced on the system by errors discovered by users and by hardware changes
- They must also incorporate new system functionality
- Release planning is concerned with when to issue a system version as a release

System Releases

- Not just a set of executable programs
- May also include

Configuration files defining how the release is configured for a particular installation

Data files needed for system operation

An installation program or shell script to install the system on target hardware

Electronic and paper documentation

Packaging and associated publicity

- Systems are now normally released on CD-ROM or as downloadable installation files from the web

Release Problems

- Customer may not want a new release of the system

They may be happy with their current system as the new version may provide unwanted functionality

- Release management must not assume that all previous releases have been accepted. All files required for a release should be re-created when a new release is installed

Release Decision Making

- Preparing and distributing a system release is an expensive process
- Factors such as the technical quality of the system, competition, marketing requirements and customer change requests should all influence the decision of when to issue a new system release

System Release Strategy

Factor	Description
Technical quality of the system	If serious system faults are reported which affect the way in which many customers use the system, it may be necessary to issue a fault repair release. However, minor system faults may be repaired by issuing patches (often distributed over the Internet) that can be applied to the current release of the system.
Lehman's fifth law (see Chapter 27)	This suggests that the increment of functionality which is included in each release is approximately constant. Therefore, if there has been a system release with significant new functionality, then it may have to be followed by a repair release.
Competition	A new system release may be necessary because a competing product is available.
Marketing requirements	The marketing department of an organisation may have made a commitment for releases to be available at a particular date.
Customer change proposals	For customised systems, customers may have made and paid for a specific set of system change proposals and they expect a system release as soon as these have been implemented.

Release Creation

- Release creation involves collecting all files and ocumentation required to create a system release
- Configuration descriptions have to be written for different hardware and installation scripts have to be written
- The specific release must be documented to record exactly what files were used to create it. This allows it to be re-created if necessary

System Building

- The process of compiling and linking software components into an executable system
- Different systems are built from different combinations of components
- Invariably supported by automated tools that are driven by 'build scripts'

System Building Problems

- Do the build instructions include all required components?

When there are many hundreds of components making up a system, it is easy to miss one out. This should normally be detected by the linker

- Is the appropriate component version specified?

A more significant problem. A system built with the wrong version may work initially but fail after delivery

- Are all data files available?

The build should not rely on 'standard' data files. Standards vary from place to place

- Are data file references within components correct?

Embedding absolute names in code almost always causes problems as naming conventions differ from place to place

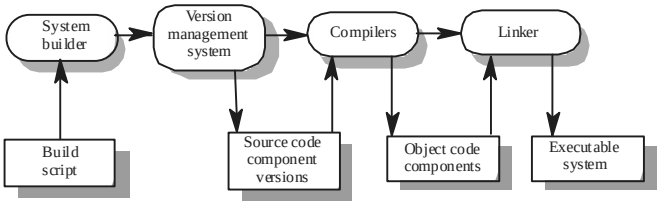
- Is the system being built for the right platform?

Sometimes must build for a specific OS version or hardware configuration

- Is the right version of the compiler and other software tools specified?

Different compiler versions may actually generate different code and the compiled component will exhibit different behaviour

System Building



System Representation

- Systems are normally represented for building by specifying the file name to be processed by building tools. Dependencies between these are described to the building tools

- Mistakes can be made as users lose track of which objects are stored in which files
- A system modelling language addresses this problem by using a logical rather than a physical system representation

CASE Tools for Configuration Management

- CM processes are standardised and involve applying pre-defined procedures
- Large amounts of data must be managed
- CASE tool support for CM is therefore essential
- Mature CASE tools to support configuration management are available ranging from stand-alone tools to integrated CM workbenches

Change Management Tools

- Change management is a procedural process so it can be modelled and integrated with a version management system
- Change management tools

Form editor to support processing the change request forms

Workflow system to define who does what and to automate information transfer

Change database that manages change proposals and is linked to a VM system

Version Management Tools

- Version and release identification

Systems assign identifiers automatically when a new version is submitted to the system

- Storage management.

System stores the differences between versions rather than all the version code

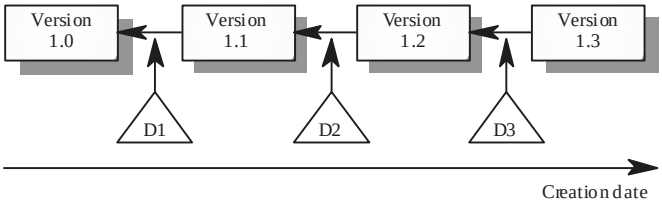
- Change history recording

Record reasons for version creation

- Independent development

Only one version at a time may be checked out for change. Parallel working on different versions

Delta-based Versioning



System Building

- Building a large system is computationally expensive and may take several hours
- Hundreds of files may be involved
- System building tools may provide

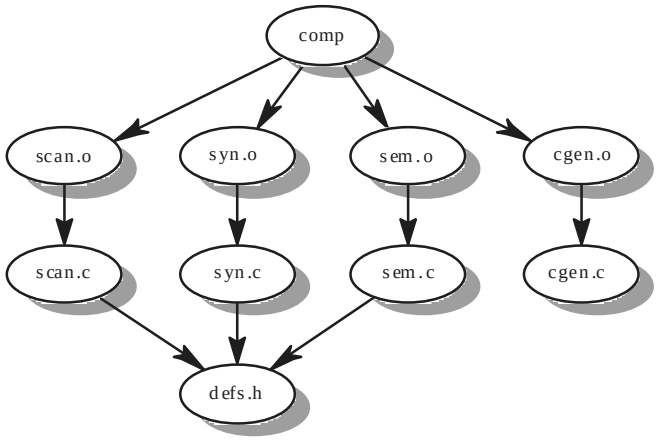
A dependency specification language and interpreter

Tool selection and instantiation support

Distributed compilation

Derived object management

Component Dependencies



Key Points

- Configuration management is the management of system change to software products
- A formal document-naming scheme should be established and documents should be managed in a database
- The configuration database should record information about changes and change requests
- A consistent scheme of version identification should be established using version numbers, attributes or change sets
- System releases include executable code, data, configuration files and documentation
- System building involves assembling components into a system
- CASE tools are available to support all CM activities
- CASE tools may be stand-alone tools or may be integrated systems which integrate support for version management, system building and change management

Activity

Explain why you should not use the title of a document to identify the document in a configuration management system. Suggest a standard for a document identification scheme that may be used for all projects in an organization.

Activity

Using the entity-relational or object-oriented approach design a model of a configuration database which records information about system components, versions, releases and changes. Some requirements for the data model are as follows:

- It should be possible to retrieve all versions or a single identified version of a component.
- It should be possible to retrieve the latest version of a component.
- It should be possible to find out which change requests have been implemented by a particular version of a system.
- It should be possible to discover which versions of components are included in a specified version of a system.
- It should be possible to retrieve a particular release of a system according to either the release date or the customers to whom the release was delivered.

Activity

Using a data-flow diagram. Describe a change management procedure, which might be used in a large organization concerned with developing software foe external clients. Changes may be suggested form either external or internal sources.

Activity

Describe the difficulties which can be encountered in system building. Suggest particular problems that might arise when a system is built on a host computer for some target machine.

Activity

A common problem with system building occurs when physical file names are incorporated in system code and the file structure implied in these names differs form that of the target machine. Write a set of programmer's guidelines, which help avoid this and other system building problems, which you can think of.

Activity

Describe five factors which must be taken into account by engineers during the process of building a release of a large software system.

Activity

Describe two ways in which system building tools can optimize the process of building a version of a system form its components.

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ENGINEERING MINDS

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